RADIUM

L. A. LEVY
H. G. WILLIS

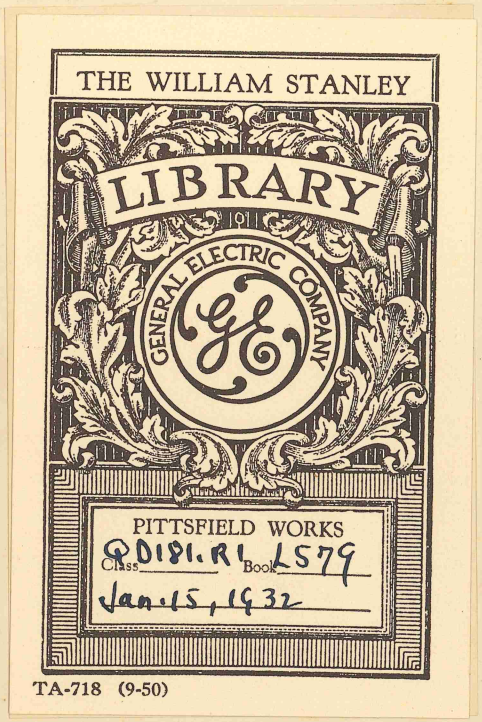
QD
181.R1
L579

PERCIVAL
MARSHALL
AND CO.

RADIUM:
and other Radio-active Elements

2/6 NET

LEONARD A. LEVY
HERBERT G. WILLIS



TA-718 (9-50)

This volume is part of the Stanley Library donated by Mrs. Wm. Stanley and should not be taken from the library.

RADIUM

AND OTHER RADIO-ACTIVE ELEMENTS.

QD
181.R1
L579

RADIUM

AND OTHER
RADIO-ACTIVE ELEMENTS

A Popular Account Treated Experimentally

BY

LEONARD A. LEVY

(FIRST IN FIRST-CLASS HONORS IN PHYSICS AT LONDON INT. B.SC., NEIL ARNOTT EXHIBITIONER AND MEDALLIST.)

AND

HERBERT G. WILLIS

FULLY ILLUSTRATED BY PHOTOGRAPHS AND DRAWINGS

LONDON
PERCIVAL MARSHALL & CO.
26-29, POPPIN'S COURT, FLEET STREET, E.C.

CONTENTS.

CHAPTER I.—THE DISCOVERY OF RADIUM: ITS EXTRACTION.

Radiation—Kathode Rays—*X*-Rays—Becquerel Rays—Crookes' Discovery—Pitchblende—Extraction of Radium—Its Distribution on the Earth 11

CHAPTER II.—THE RADIUM EMANATION.

The Emanation—Its Nature—Disintegration of the Radium Atom—Its Conversion into Helium—Theory of Solar Radiation due to Radium—Properties of the Emanation—Effect of Temperature 22

CHAPTER III.—PHYSICAL EFFECTS (ELECTRICAL AND MAGNETIC).

Nature of Rays Emitted by Radium—Ionization—Charge and Magnetic Deviation of β Rays—Charge and Magnetic Deviation of α Rays—Theory of Atmospheric Electricity and Terrestrial Magnetism Due to Radium 33

CHAPTER IV.—PHYSICAL EFFECTS (*continued*).

Luminous Effects—Spinthariscope—Fluorescent Substances—Thermal Effects—Thermo-luminescence—Penetrative Powers—Absorption of Gravitational Energy—Induced Radio-activity 49

CHAPTER V.—CHEMICAL EFFECTS.

Effect on Photographic Plates—Colourations of Glass, Paper, etc.—Effect on Solutions of Iodoform in Chloroform—Effect on Compounds of Iodine—Reducing Effect—Molecular Changes Produced—Relation to other Elements—Atomic Weight Determination 69

959

CHAPTER VI.—ACTIONS ON ANIMAL LIFE AND LIVING TISSUES.

Effect on Plants and Seeds—on Spermatozoa—on Ova—on Eggs of the Sea-urchin—on Larvæ and Embryos——on Animals of Low Type—Motor Action—on the Eye—on the Skin—on Lupus and Cancer—Radium Apparatus for Cancer 77

CHAPTER VII.—OTHER RADIO-ACTIVE ELEMENTS.

Uranium—Its Extraction—Appearance and Nature—Emanation—Uranium X-Rays Emitted—Their Effects 89

Thorium—Nature—Thorium X—Emanation—Induced Radio-activity—Rays Emitted—Carolinium and Berzelium—Connection with Actinium 91

Polonium—Discovery and Extraction—Physical Attributes—Rays Emitted 95

Actinium—Discovery—Emanation—Rays 96

Hofmann's Radio-active Metal 97

APPENDIX.—EXPERIMENTAL APPARATUS ... 98

INTRODUCTION.

About sixty years ago, when the first telegraphic lines were erected, people marvelled at the seeming miracle. Later on electric light was invented, and still later the telephone. The last decade has witnessed discoveries which have rendered possible the photography of the bones of a living being; the demonstration of the motion of the heart on a screen by *x*-rays; and also the transmission of messages without wires. The latest marvel of science is the discovery of the new series of radio-active elements.

The most active and wonderful of these elements which has up to the present been investigated or obtained in sufficient quantity for investigation is called "Radium." The properties of Radium, and its allied elements, are so unique and astounding, that this alone is sufficient reason to account for the interest which it has excited.

In addition to this, however, radium is reputed to have great therapeutical properties. Experiments are now being carried out, with partial if not complete success, to combat by means of radium diseases hitherto considered incurable.

Many articles on radium have appeared in various papers, scientific and otherwise ; but as yet no complete correlation of the many facts has been published.

We have endeavoured to treat the subject in an experimental and practical way, but have not attempted to relate or explain the various theories of the sources of the radiations.

It is generally conceded that a thorough grasp of scientific subjects can only be gained by actually performing experiments illustrating the various laws and properties under consideration. For this reason we believed that a book on the subject of " Radium " would be more interesting and readily understood if treated in an experimental way.

Every experiment described is easy to carry out. The majority can be performed even with so small a quantity as $2\frac{1}{2}$ milligrams ($\frac{1}{26}$ grain approximate). If a larger amount were used the results would naturally be more rapidly and satisfactorily arrived at.

Radium has upset so many scientific theories that a new era in science may almost be said to have commenced : certainly, the subject of radio-activity opens up a new chapter in physics.

Although at first Radium was thought to solve the seemingly impossible problem of perpetual motion,

it is now known that, whilst not accomplishing this, it holds out immense possibilities.

We have treated the subject under the headings of physical, chemical and other effects rather than under those of the various rays, believing that this mode of treatment would be more generally interesting.

RADIUM

AND OTHER RADIO-ACTIVE ELEMENTS.

CHAPTER I.

THE DISCOVERY OF RADIUM: ITS EXTRACTION.

Radiation—Kathode Rays—*X*-Rays—Becquerel Rays—Crookes' Discovery—Pitchblende—Extraction of Radium—Its Distribution on the Earth.

BEFORE considering the various radiations, it may be advisable to state clearly what is meant by the term "radiation." A radiation may be a motion of the ether (the hypothetical medium which is supposed to permeate all space) or a stream of small charged particles proceeding from an external centre.

The discovery of radium was scarcely accidental, but rather the result of careful experiments by various scientists. These experiments did not at first seem to have much connection, but can now be correlated. It will be shown how each experiment and discovery, though slight in itself, has helped to build up our present knowledge of the subject of

radio-activity, now occupying so much attention in the scientific and public mind of to-day.

Radium rays having so many properties in common with the kathode and *x*-rays, and the discovery of *x*-rays being the first step towards the discovery of radio-active elements, it may be advisable to briefly consider these two classes of radiation.

If an electric discharge from an induction coil or a Wimshurst machine be passed between two terminals in a tube filled with air at atmospheric pressure, vivid sparks will pass. Let us suppose the glass tube is connected to an air pump and gradually exhausted; it will be found that, as the pressure of the air in the tube lessens, remarkable changes take place in the appearance of the discharge. As the exhaustion proceeds, the discharge takes the form of a luminous column of gas. When in this state, it forms one of the Giessler tubes so familiar to all interested in electricity. On further exhaustion the luminous discharge becomes stratified, and a dark space appears in the neighbourhood of the negative or kathode terminal.

The dark space grows in size on still further exhaustion, and when it has enlarged sufficiently to reach the sides of the glass tube, the latter become fluorescent. Faint dark blue streams can be seen within the dark space, leaving the kathode (which in the tubes usually employed is a spherical piece of aluminium) and converging towards its centre, where the positive or anode terminal is placed.

These blue streams compose the so-called kathode

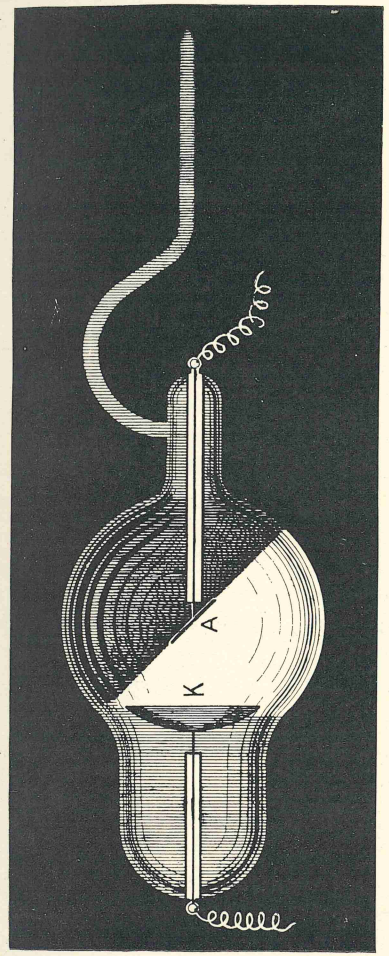


PLATE I.—APPEARANCE OF X-RAY TUBE WHEN WORKING.

rays. They apparently consist of streams of negatively-charged particles moving with a very great velocity. This velocity has been directly measured, and found to be about 50,000,000 metres per second (31,000 miles approximately). The mass of the particles has been estimated to be about $\frac{1}{1000}$ of the mass of a hydrogen atom (Chapter II).

Another remarkable change takes place after the exhaustion of the tube has been carried to the point at which the dark space reaches the anode A. The whole of the glass on the kathode side of the plane drawn through the anode becomes fluorescent, shining with a bright yellowish-green light; the space on the other side of the anode appearing comparatively dark. The appearance of the tube when in this condition is shown by Plate I.

Professor Röntgen discovered that the glass when in this condition emitted a radiation which was capable of penetrating flesh, and many other substances opaque to light. He termed these rays "*x*-rays," but they are often called Röntgen rays, in honour of their discoverer. The effects produced by *x*-rays are well known.

It is believed that the *x*-rays are produced by the action of the kathode rays upon the glass of the tube. In 1896, Poincaré, a French mathematician, suggested that as the source of the *x*-rays was apparently the fluorescence of the glass tube, then perhaps *x*-rays always accompanied fluorescence.

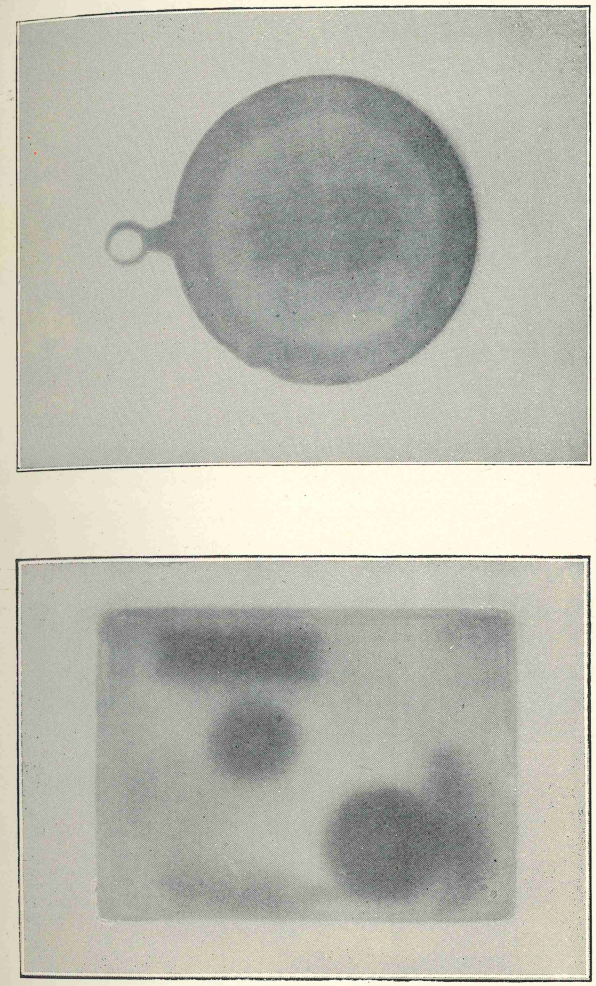
This suggestion was immediately taken up by Henry and Becquerel. It has for a long time been

known that many substances, after exposure to sunlight, appear luminous in the dark. This property is called *phosphorescence*. It is by no means unique, being possessed in a greater or less degree by very many substances. Amongst these may be mentioned calcium, barium and zinc sulphides, also the familiar luminous paint.

Henry, while experimenting with various substances, in order to discover whether *x*-rays were produced in any other way, found that, in addition to the emission of luminous rays, zinc sulphide emitted non-luminous radiations. These latter were capable of traversing several sheets of black paper or other substances of low density, and subsequently of affecting a photographic plate.

Becquerel, following up this discovery, found that uranium salts acted in a similar manner. He placed salts of uranium upon photographic plates, well wrapped up and protected from ordinary light. He also placed layers of foil of different metals between the uranium salts and the plate. In every case the results obtained were the same—the plates were affected as though they had been acted upon by light ; technically they were said to be " fogged." An example of a plate fogged by uranium nitrate is shown in Chapter VII.

The next advance was purely accidental. Becquerel found that similar effects were obtained in the dark. He placed some uranium salts on a photographic plate protected from light, intending to expose the salts to sunlight. Owing to lack of



(A) Objects in cardboard box. (B) Aluminium medal, showing embossed shield and rim.

PLATE II.—RADIOGRAPHS TAKEN BY BECQUEREL RAYS.

the latter they were not exposed, and it then occurred to him to develop the plate. This, after development, was found to be fogged just as though the uranium salts had been exposed to light. Becquerel also discovered that the non-fluorescing ura-*nous* salts as well as the fluorescent ura-*nic* salts possessed this property.

Uranium salts which had been prepared in the dark, and which had never since their preparation been exposed to light of any description, produce similar results. They were equally as active as those prepared in the ordinary way.

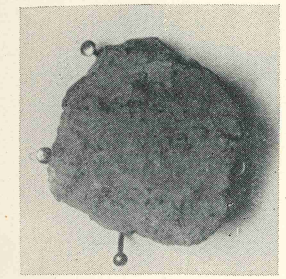
The rays emitted by uranium salts were called Becquerel rays, after their discoverer. Plate II (A) is a radiograph of some objects in a cardboard box. This was taken by standing the box on a photographic plate and placing a uranium screen (described in the Appendix) above the box. The Becquerel rays have easily traversed the box, but have not to any extent penetrated the metal and other objects therein contained; a "shadow" of the latter is, therefore, cast on the plate. Plate II (B) is a radiograph of an aluminium medal obtained in an exactly similar manner. The rays traverse the thicker portions less readily than the thinner parts of the medal. A shadow is cast which shows, roughly, the outline of the embossed design.

Crookes, who made the next advance, showed that the radiation proceeded not from the uranium salts, but from some unknown impurity. By fractional crystallisation (see below) of uranium salts, two

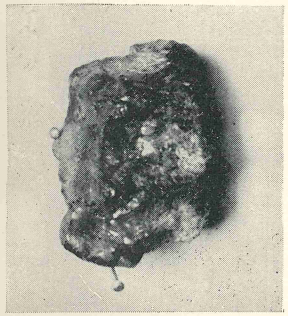
different portions could be obtained—one of which was, and the other was not, radio-active. He showed that the uranium salts of commerce could be purified from radio-activity by dissolving in ether and then crystallising out. He proposed to call the radio-active residue U.x. (see also Chapter VII).

The radio-activity was proportional to the amount of uranium present, and the metal itself was most active. It was at this stage that Madame Curie took up the subject of radio-activity. She discovered that the minerals pitchblende, Plate III (A), and chalcolite, Plate III (B), were even more active than uranium itself. It is, therefore, evident that these two minerals must contain some radio-active constituent, considerably more radio-active than uranium itself. Plate IVA (1) is the result of placing a piece of Bohemian pitchblende on a photograph plate, well wrapped up and protected from ordinary light, the exposure being seventy-two hours. Plate IVA (2) was obtained in an exactly similar way, an aluminium disc $\frac{1}{8}$ in. thick being placed between the pitchblende and the plate. It is evident that the effect produced by the Bohemian pitchblende in three days is greater than that produced by uranium nitrate in seven days [see Plate XXII (A)]. Plate IVB (1) and (2) were obtained respectively with Cornish pitchblende and chalcolite.

Pitchblende is a black mineral in shape and colour, very like hardened pitch—hence the name "pitchblende." Chemically it is a fairly pure oxide of uranium, and is extensively used as a source of



(B) Chalcolite.



(A) Pitchblende.

PLATE III.—RADIO-ACTIVE MINERALS.

uranium oxide for the manufacture of uranium glass.

Chalcolite is a brittle green mineral of earthy appearance. It contains copper, uranium, phosphorus, oxygen, and hydrogen. It is found, together with pitchblende, at Redruth in Cornwall.

Madame Curie tried to analyse pitchblende, in order to separate from it a radio-active constituent, or constituents. Her method was to split up the ore into various groups. The ore was first fused with sodium carbonate and then dissolved in hydrocholoric acid. The metals of the lead group present in pitchblende, such as lead, copper, and bismuth, were removed by precipitation with hydrogen sulphide. The other metals, such as iron, zinc, &c., were also removed by precipitation with suitable reagents. A radio-active element combined with bismuth and sulphur was isolated. This was called "Polonium," in honour of Madame Curie's native country (for further details concerning polonium see Chapter VII).

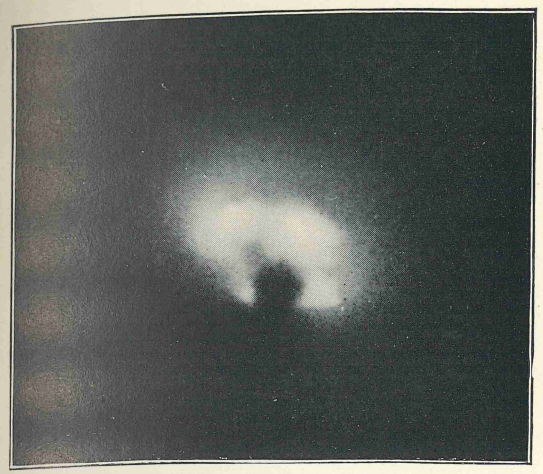
A mixture of barium and radium chlorides remained in solution after the removal of the metals of the first two groups. The amount of radium chloride present was exceedingly small. The last and most tedious process of extraction was to obtain the radium chloride as free as possible from barium chloride. If there were a chemical method whereby radium might be precipitated without the precipitation of barium, or *vice versa*, then doubtless radium would become much cheaper, and certainly would be more easily extracted. The present process of extraction, how-

ever, is so long and so difficult that radium can never become cheap whilst it is prepared by present methods.

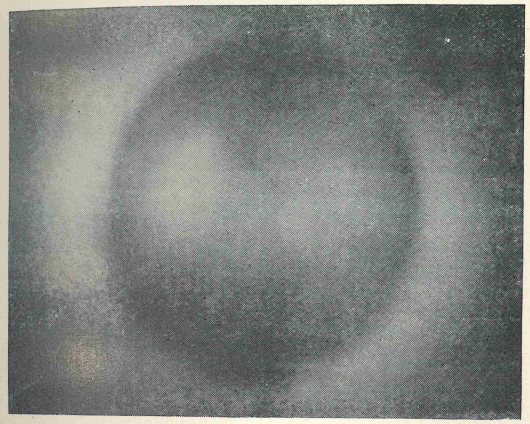
The process of extraction of radium chloride from barium chloride is called " fractional crystallisation." The method depends upon the fact that radium chloride is slightly less soluble in water than barium chloride ; therefore, if a mixture of these two chlorides be dissolved in water or alcohol, the first crystals which are deposited are richer in radium than those still in solution. They will also contain the majority of the radium. The first crystals are collected, again dissolved, and allowed to crystallise ; the first portion being collected as before. This process is repeated many times until the crystals deposited are practically pure radium chloride.

The crude radiferous barium chloride first obtained from the pitchblende has a radio-active intensity of not more than forty times that of uranium. After the first crystallisation it has an intensity of about five times that value, *i.e.*, about 200. This holds good throughout the process of crystallisation, the first crystals always having an intensity of about five times that of those obtained at the preceding crystallisation.

Pure radium chloride has an intensity of about 1,500,000 times that of uranium. This radium chloride (or bromide) presents no very striking appearance. A few whitish or brownish crystals or a fine powder is all one sees. Plate V is a photograph of some radium in a glass tube—it may be dis-



(1) Fogging produced by pitchblende.



(2) A similar experiment to above, but through aluminium disc.

PLATE IVA.—EFFECT OF RADIO-ACTIVE MINERALS ON PHOTOGRAPHIC PLATES.

tinctly seen at the bottom of the tube in the left-hand side.

The crystals glow in the dark with a faint luminosity, not so bright as that emitted by a small piece of phosphorus. (The cause of this luminosity is explained in the next Chapter.)

The bromides of barium and radium are more easily separated by crystallisation than their chlorides. The time required for the preliminary treatment is reduced from three months to one month, if bromides be used instead of chlorides. This is the basis of the process of extraction employed by Giesel. The carbonates obtained as above are boiled with hydrobromic acid instead of hydrochloric.

The residue from the manufacture of uranium oxide from pitchblende, contains considerably more radium than pitchblende itself. The amount of radium even in this so-called rich ore is extremely small—the ore is said to be *rich* in radium if it contains one part of radium in 10,000,000, by weight.

The largest quantity of radium bromide yet obtained from any ore is about 4 grains per ton of ore, which was extracted by Giesel. The residue comes exclusively from a place called Joachimsthal, in Bohemia, where there are very large deposits of pitchblende. It was for years discarded as valueless, anybody who so wished being at liberty to remove it. It has also been reported that large quantities have been thrown away by a London chemist. What was formerly regarded as rubbish is now a very

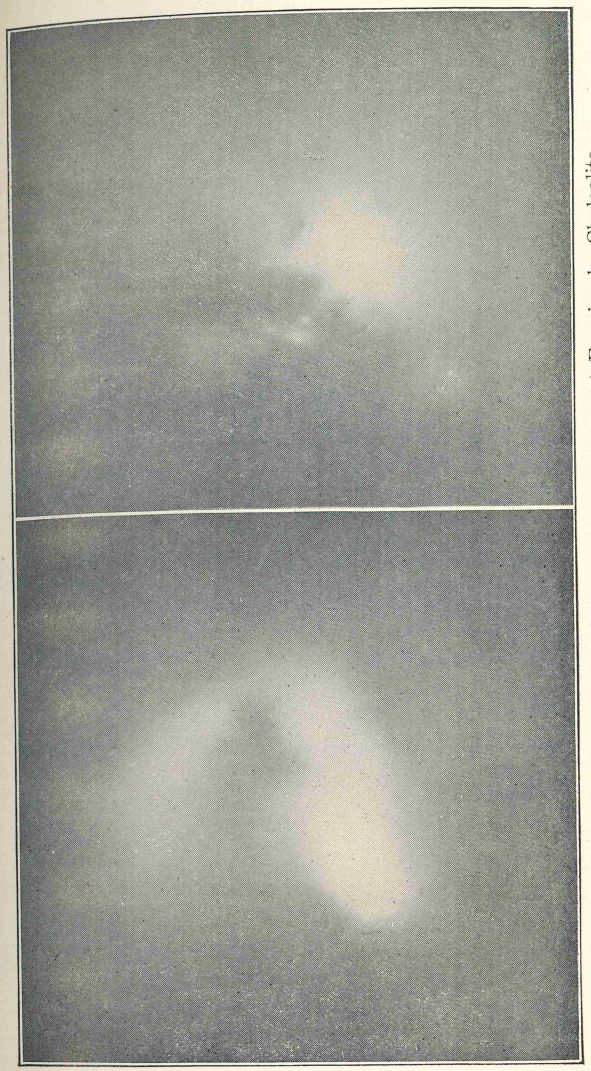
valuable asset, and the Austrian Government has forbidden for the present the exportation of the residue.

Radium is fairly well distributed on the earth's surface, although, as a rule, it is only present in very minute quantities. In England it has been discovered in the deposits around the hot springs of Bath and Buxton. It is also present in fairly large quantities in Cornish pitchblende, and projects are afoot for the manufacture of English radium from this source.

Radium has been discovered in the mineral carnallite, in Utah, U.S.A. In Texas there appears to be a large deposit of radiferous material, although whether radium is present in sufficient quantity for profitable extraction is as yet unknown. Radium is also found in various places in Saxony.

It has also been noticed that the air from deep borings in the earth is radio-active. This appears to indicate the presence of radium in considerable quantity deep down in the earth, which may be expected; it being probable that all heavy metals become more plentiful as the interior of the earth is further penetrated.

Wherever the term radium is used it must be understood to refer to either of its salts, *e.g.*, the chloride or bromide. The metal radium has not as yet been isolated—were it to be so, it would immediately be oxidised on contact with the atmosphere. It is probable that it would present a similar appearance to that of the metal barium, to which it is so



(1) Fogging by Cornish Pitchblende. (2) Fogging by Chalcolite.

PLATE IVB.—EFFECTS OF RADIO-ACTIVE MINERALS ON PHOTOGRAPHIC PLATES.

closely allied in many of its chemical and physical attributes.

Sir William Ramsay has obtained radium in an alloy with mercury and barium. From this amalgam, the mercury can be driven off by heat. Later on the barium may, perhaps, be separated also, leaving pure metallic radium.

CHAPTER II.

The Radium Emanation.

The Emanation—Its Nature—Disintegration of the Radium Atom—Its Conversion into Helium—Theory of Solar Radiation due to Radium—Properties of the Emanation —Effect of Temperature.

Many of the remarkable properties of radium are due not really to the radium itself, but to the "emanation" given off. It was found shortly after the discovery of radium that a certain "something" was being continually emitted, although where it came from, or how produced, was not then known. It was proposed to call this "something" the "emanation" of radium. This term is still in vogue, although a great deal more is now known about it. The name is quite a happy one, as it absolutely does "emanate" from the radium. Before proceeding to discuss the properties of the emanation, it may be advisable to give a slight outline of the views now current among scientists as to why the radium does give off this emanation, and does not remain passive like most elementary substances.

All substances are supposed to be composed of molecules (or collections of atoms), the latter being the smallest portion of matter which can take part

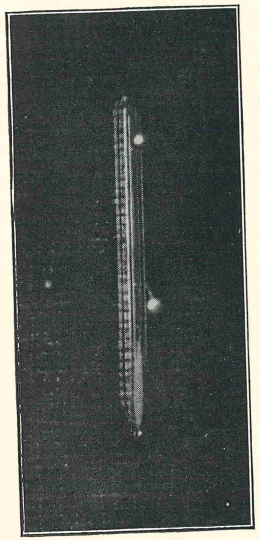


Plate V.—A tube of radium bromide.

[This is a photograph of a five-milligram tube, taken full size. The radium can be seen on the left at the bottom of the tube.]

in any chemical change. The molecules in compounds are composed of different kinds of atoms ; in elements, such as gold, silver, copper, etc., they are composed of similar atoms. All elements have a certain weight, called the "atomic weight." The number expressing the atomic weight of any element merely denotes the number of times that the weight of an atom of that element is greater than that of an atom of hydrogen (the lightest of all known substances). When we say that oxygen has an atomic weight 16, we imply that its atom is 16 times as heavy as a hydrogen atom. There are some substances the molecule of which is very complicated, containing nearly 100 atoms. If a substance could be produced the molecule of which contained, say, 600 atoms, it is almost certain that it would decompose ; the molecule would be unstable. Just as there seems to be a limit to the number of atoms in a molecule of a compound substance, *i.e.*, to its molecular weight, so there seems to be a limit to the atomic weight of an element.

It is believed that elements of high atomic weight may be slowly changing into elements of low atomic weight. Thorium, atomic weight, 232; uranium, atomic weight, 240 ; radium, atomic weight, 258 ; all emit an emanation—*i.e.*, they seem to be changing into something else. The consideration of thorium and uranium is reserved for Chapter VII.

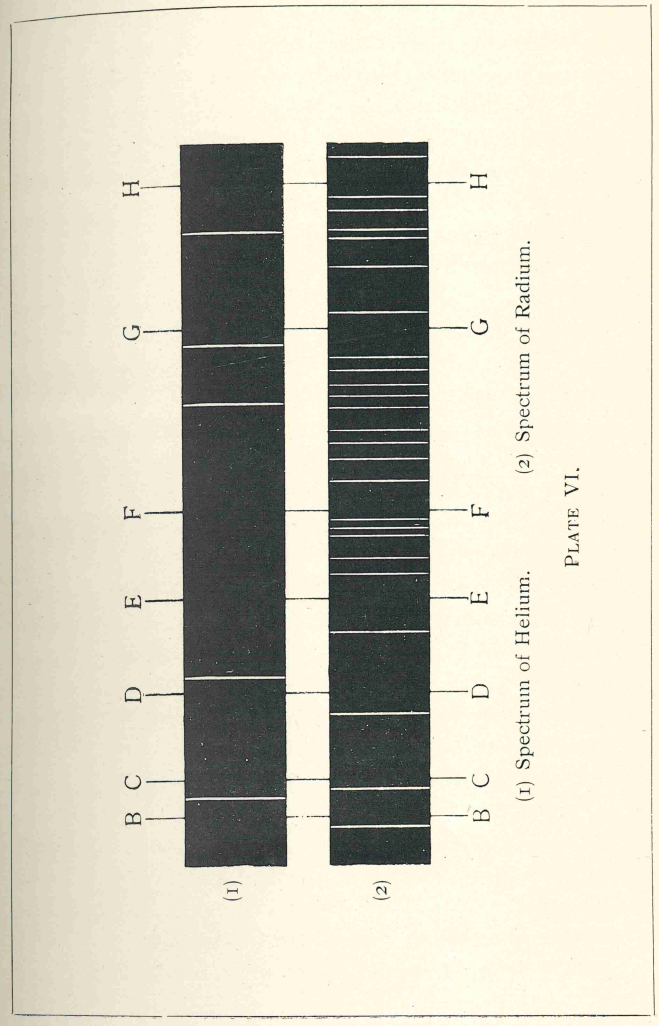
Energy is required in the formation of a molecule ; therefore, when the molecule breaks up, the energy previously acquired is liberated, generally in the

form of heat. In the case of radium, the energy liberated by the dissociation of the molecules is emitted—some in the form of heat, and some in the form of radio-activity. Its atom is believed to disintegrate, and in so doing to form the emanation. The atomic weight of the emanation has been ascertained by Rutherford to be about 100, *i.e.*, less than one half of that of radium.

It was found that after the emanation had been in existence for a few days it began to change into an element already well known—a gas called helium. As radium is continually forming a substance which turns into helium, it is evident that radium itself is turning into helium, the atomic weight of which is 4. This is at present the only known example of the conversion of one element into another.

This change gives occasion for much speculation. Can the process be reversed? Is it possible to convert an element of low atomic weight, such as helium (4) or hydrogen (1), into one of high atomic weight, such as gold (197)? No one can at present answer this question. Indeed, it seems more probable that, if any change at all is taking place, gold is turning into some element of low atomic weight. Thus, although the dream of the old alchemists (who sought to transform baser metals into gold) may not be an impossibility, it seems at present more likely that, if any change at all is taking place, it is in the opposite direction.

Helium was first discovered in the sun in the year 1868, by the celebrated astronomer Jannsen. It may



(1) Spectrum of Helium. (2) Spectrum of Radium.

PLATE VI.

be asked, how was it possible for Jannsen to discover helium in the sun, 92 million miles away, and also, how were the exceedingly minute quantities of helium (produced by the decay of the emanation) recognized? In each case the method employed was the same, namely, that of spectrum analysis.

It is generally known that ordinary white light is composed of seven primary colours—red, orange, yellow, green, blue, indigo, and violet, composing what is known as the spectrum. When ordinary white light is passed through an instrument called a spectrometer, it is dispersed by means of a prism or grating into a spectrum. If instead of admitting white light through the spectrometer, we admit the light from a glowing gas or vapour, we merely see a succession of thin lines of different colours in certain definite places, in the position formerly occupied by the continuous spectrum. *No two elements give the same lines or combination of lines.* Any element or mixture of elements can thus be recognised by means of its spectrum.

It was by this means that Jannsen, when observing the outer portion of the sun, called the chromosphere, found a new line in its spectrum, afterwards called D_3. This line is bright yellow, and did not at that time correspond to any known terrestrial element. The element corresponding to this line was called helium, from *Helios*, the Greek for the sun. Plate VI (1) shows, diagrammatically, the spectrum of helium, the spectrum of radium being shown underneath. Their dissimilarity is very apparent. The emanation has

little or no spectrum, except a very faint light in the green.

Helium was not discovered upon the earth until 1895, when it was found occluded in certain rare minerals—clevite and tergusenite. In every case where helium has been found occluded, a radio-active substance has also been found in the mineral. The assumption has therefore been made that, since radium is continually changing into helium, where there is helium there is still, or must have been, radium ; hence the obvious suggestion has been made that there is radium in the sun, and even that it plays a large part in the solar radiation. It has been calculated that 3·6 grammes of radium per square metre of the sun's surface (*i.e.*, about 50 grains per square yard) would amply suffice to supply all the heat the sun radiates.

This throws a new light upon the age of the sun. Lord Kelvin, basing his arguments upon the consideration that the sun is a slowly cooling white-hot body, stated that it could not possibly be more than 20 million years old. Geologists, to account for the deposition of continents and the period of elevation, demanded at least 100 million years. The discovery of radium has thrown quite a new light upon the question. If the solar radiation is due either entirely, or in part, to the presence of radio-active bodies in the sun, it may be considerably older than was before considered possible by the physicist.

The idea may occur to many that as radium gives off rays which are harmful to man, would the presence

of so large a quantity of radium in the sun be detrimental, if not fatal, to life on the earth ? Strutt and Joly have considered the problem from a mathematical point of view, both coming to the conclusion that it is very improbable that any of the radium rays could reach us at our great distance from the sun.

The supposition that where helium is, radium still is, or must have existed, gains additional support from the recent discovery of radium in the deposits around the hot springs at Bath. A short time ago the waters of the Bath springs were found to contain helium.

The emanation has several strange properties in addition to that of turning into helium. It is a gaseous substance, incapable of penetrating metal, glass, &c., but readily diffusing through porous substances such as cardboard. It behaves like other radio-active gases and vapours, and, unlike the gaseous ions which they produce in their path (by splitting up the air molecules) (see Chapter III, on "Ionization"), passes easily through plugs of cotton wool, and bubbles through hot or cold water, or sulphuric acid, without absorption. It is capable of condensation by extreme cold (see below). It loses its radio-activity during its change into helium, losing about one-half in four days, and practically all in a month.

The emanation is self-luminous, shining in the dark with a greenish-blue light. This can be beautifully shown if a mercury air-pump be worked with gas rendered luminous by the emanation : the motion

of the gas and the gradual production of a vacuum being easily visible in the dark. It seems probable that the luminosity of radium itself is due to the emanation mixed up with it. If radium be heated, the emanation is at first emitted profusely, but the evolution stops at a red-heat. The radium, on cooling, appears to have lost its luminosity, which it does not recover for several days. Heating appears to drive off the emanation, and thus to destroy the luminosity of the radium, the latter not reappearing until sufficient emanation has been reformed.

The following is the method usually employed to obtain the emanation for experimental purposes: Radium bromide sets up a kind of electrolysis in solution (see Chapter V). Hydrogen and oxygen are therefore evolved from a solution of radium bromide in water. These gases carry with them exceedingly minute traces of the emanation. The hydrogen and oxygen are absorbed by suitable chemical reagents, the emanation alone remaining. At best, however, only very minute quantities can be obtained. The most drastic chemical treatment has entirely failed to alter or destroy the emanation.

The heating effect of radium is very probably due to the emanation. Its demonstration, &c., is discussed in a future chapter—only its relation to the emanation need here be considered. A stream of air charged with radium emanation is passed over a thermo-electric couple. This consists of two different metals—generally bismuth and antimony—joined together. Should one junction be warmer than the

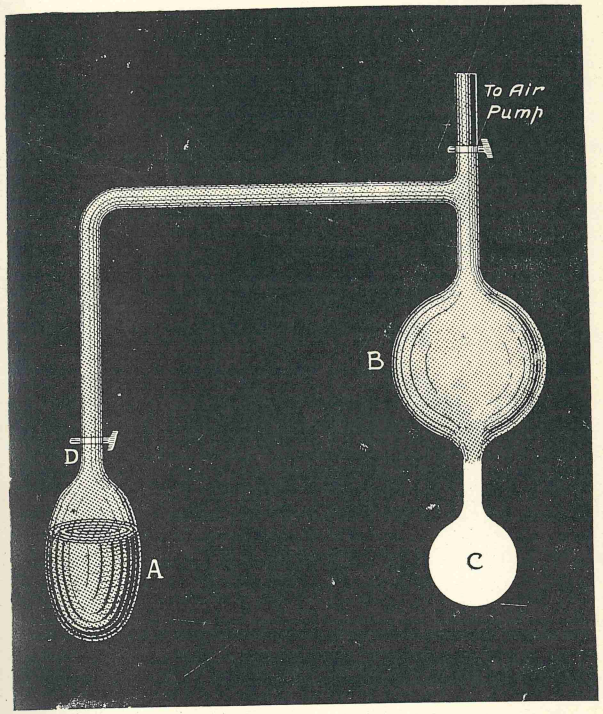


PLATE VII.—A DIAGRAM OF CURIE'S CONDENSATION EXPERIMENT, SHOWING APPEARANCE OF APPARATUS WHEN THE BULB C IS IMMERSED IN LIQUID AIR.

other, a current of electricity will flow from the antimony to the bismuth across the cold junction. One junction of the thermo-electric couple is kept at a low negative potential. In this way the emanation, being charged with positive electricity, is condensed upon it, because unlike charges attract one another. The two junctions, one with the emanation condensed upon it, and the other without, are placed into two separate vessels of similar uniform temperature. A galvanometer is placed in the circuit with the thermo-couple, this being simply an instrument to indicate any current which passes between the two points.

Provided the two junctions remain at the same temperature, no current will flow, this being indicated by the non-deflection of the galvanometer. After a short time, however, it is found that there is a flow of current indicated by the deflection of the galvanometer. The direction of the current proves that the junction, on which the emanation is condensed, is being heated. The heating effect continues as long as the luminosity remains, *i.e.*, until the emanation is quite decayed. This proves that there is a heating effect due to the emanation.

A striking experiment with the emanation, due to M. Curie, shows that it can excite fluorescence in foreign bodies, and also that it can be condensed by extreme cold.

A glass bulb A (Plate VII) contains some radium bromide in solution. As explained above, this causes electrolysis and evolution of the radium emanation.

The bulb A is connected, by means of a bent tube, to the bulbs B and C, each coated with sulphide of zinc. The stop-cock D is first closed; the air is then removed from the bulbs B and C by means of an air-pump. On opening the stop-cock D, the zinc sulphide in the bulbs B and C shines with a yellowish-green fluorescence.

As the fluorescence did not occur until the stop-cock was opened, it is quite evident that it is not due to the radium rays: these can quite easily traverse the intervening glass of the bulbs A, B, and C. It must have been due to "something" that was stopped by the closed stop-cock, *i.e.*, something of the nature of a gas. This proves that the emanation is gaseous in character. It appears also that the emanation and not the radium rays caused the zinc sulphide to fluoresce. This is not strictly correct; the explanation of the observed fact is given further on. The light produced by the fluorescence is very vivid, and plainly visible some distance away.

The second portion of the experiment, showing that the emanation is capable of condensation by extreme cold is even more striking. The bulb C is immersed in a bath of liquid air. After a short time, the fluorescence of the zinc sulphide in the bulb B, (not immersed in liquid air) is observed to be getting dimmer and dimmer, whilst that of the bulb C, which is immersed, is observed to be correspondingly brighter. After a certain period, the bulb B is scarcely luminous, all the light appearing concentrated in C.

On removing C from the liquid air bath, the bulbs gradually regain their former appearance.

As the immersion of the bulb C in the liquid air bath produced a great concentration of light in that bulb and a corresponding diminution in the other, it appears as if the extreme cold of the liquid air removed or condensed the emanation from the upper bulb into the lower, the corresponding increase of light being due to practically all the emanation being concentrated in C. This is no doubt the correct explanation, for it has been proved that the emanation can be condensed by extreme cold into a white solid.

We have now to refer again to the fact that the luminosity did not appear in the bulbs until the stop-cock was opened, thus *apparently* proving that the fluorescence was produced not by the radium rays, but by the emanation.

The emanation has the property of condensing on surrounding objects, and bestowing upon them the property of radio-activity.

This induced radio-activity lasts until the emanation decays. The substances rendered radio-active appear to possess, for a short time, the actual properties of radium itself. This property of induced radio-activity is treated more fully in Chapter IV.

In addition to the emission of an emanation, radium is continually emitting three different classes of rays, denoted respectively by the first three letters of the Greek alphabet. These rays have many remarkable properties, amongst others that of causing zinc

sulphide to glow. How is it, then, that the zinc sulphide in the bulbs B and C did not glow before the stop-cock was opened, as the rays could easily traverse the intervening glass ?

The following is the probable explanation, and, at the same time, it shows that the emanation is probably the source of the α-, β-, and γ-rays—*i.e.*, the three classes of rays emitted by radium.

Before the stop-cock is opened, the only action the radium can exert upon the zinc sulphide is by means of its rays, which have to traverse a considerable layer of air and glass, and in so doing suffer considerable absorption. Any fluorescence which may thus be produced is too faint to be visible. When the stop-cock is opened, the emanation escapes and speedily reaches the zinc sulphide. In this case the rays emitted by the emanation are in very close proximity to the zinc sulphide, and they suffer practically no absorption. The glow is therefore very vivid.

CHAPTER III.

Physical Effects (Electrical and Magnetic).

Nature of Rays Emitted by Radium—Ionization—Charge and Magnetic Deviation of β-Rays—Charge and Magnetic Deviation of α-Rays—Theory of Atmospheric Electricity and Terrestrial Magnetism Due to Radium.

Before considering the electrical and magnetic effects in detail, it may be advisable to discuss the nature of the various rays, and the views now held by scientists as to their composition. Radium, as already stated in the preceding chapter, emits three classes of rays—the α, the β, and the γ.

The α-rays are believed to consist of streams of minute particles, thrown off from the radium with the immense velocity of 12,500 miles per second. They are supposed to be actual helium atoms. Each carries a small positive charge of electricity. They are only very slightly deviated by a magnetic field. They ionize gases, that is to say, they render them conductors of electricity. Certain minerals become luminescent under their action.

The β-rays are supposed to consist of exceedingly minute particles, shot off at over five times the speed of the α particles, *i.e.*, at 63,000 miles per second. They are deviated considerably by a

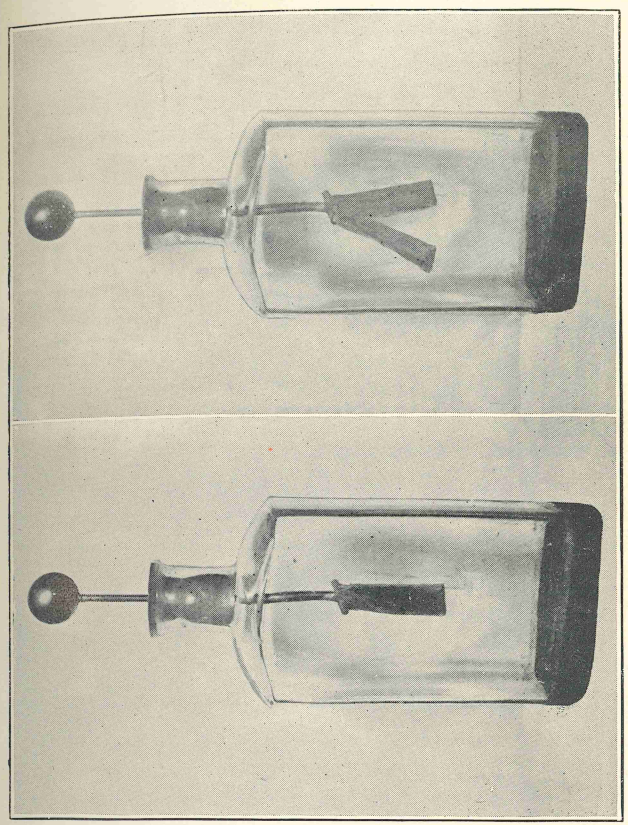
magnetic field, and cause slight ionization in gases. Each β particle carries a small negative charge of electricity. Certain minerals also become luminous when under the action of these rays.

Some idea of the relative sizes of the α and β particles may be gathered from the following illustration :—Suppose a collection of α-ray particles—equal in size to a single drop of water—to be magnified to the size of the earth ; each α particle would then appear probably somewhat larger than small shot ; whilst the β-ray particles would still be invisible to the naked eye, being only one thousandth part of the size of the α particles.

Very little is known about the γ-rays. They are believed to be similar to the Röntgen or x-rays. They do not carry any charge of electricity, and are not deviated by a magnetic field. They have only a slight ionizing effect. They are probably produced by the action of the α- and β-rays upon surrounding objects ; just as the x-rays are produced by the action of the Kathode rays upon the glass tube (see Chapter I).

All three kinds of rays differ from light rays, in having no direct sensitive effect upon the retina of the eye. The γ-rays are similar to light and x-rays, inasmuch as they travel in straight lines, casting a shadow of objects (opaque to them) in their path.

It may be asked whether the radium loses in weight through the emission of the emanation and particles. At present no very satisfactory answer can be given



(A) Electroscope discharged. (B) Electroscope charged.

PLATE VIII.—IONIZATION EFFECTS.

to this question. The loss of weight is exceedingly minute, and has been variously estimated by scientists. The opinion ranges between the limits of a loss of weight of one-thousandth part in one million years, and one thousandth part per year. Recent experiments give to radium a life of a little over one thousand years.

It was soon observed that after the radium radiations had passed through a gas, the latter became a conductor of electricity. This property is shown by the rays discharging a charged gold-leaf electroscope.

A gold-leaf electroscope consists, in its simplest form, of two strips of gold-leaf (see Plate VIII), suspended side by side from a brass rod which communicates directly with the knob outside. The gold leaves are enclosed in a glass case in order to protect them from air currents.

One of the fundamental properties of electrified bodies is, that if they be electrified similarly they repel one another. The knob of the electroscope is charged by touching it with an electrified body (such as an ebonite rod rubbed with silk). The finger is placed at the same time on the knob to conduct the "free" electricity produced to the earth, and then withdrawn before the removal of the electrified body. This sets free the previously bound electricity, and, as like electrified bodies repel one another, the leaves fly apart.

If, whilst the electroscope is charged, a radium salt be brought near, the leaves will, in a few seconds,

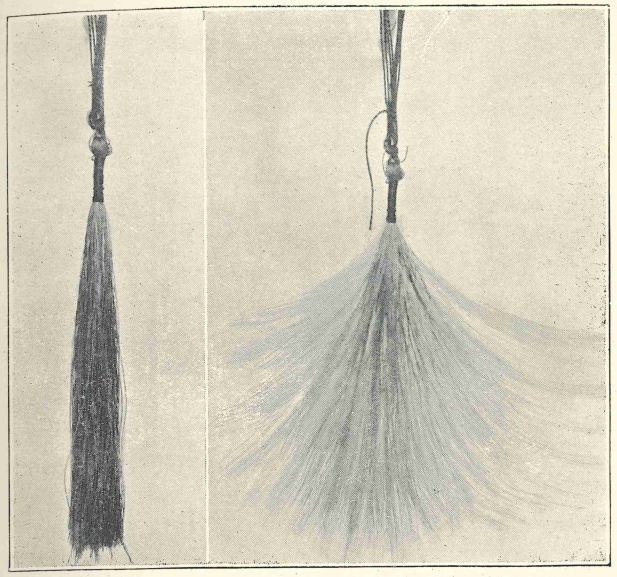
collapse. The electricity must have been discharged as the leaves collapsed; and the only way it could have escaped is by atmospheric conduction. Hence, it is evident that radium makes air a conductor of electricity.

This conclusion can be proved with absolute certainty, by repeating the experiment with the electroscope under the receiver of an air-pump. If no radium is near, the receiver may be exhausted and filled again, without in the least degree affecting the divergence of the leaves. If the electroscope be charged, the leaves therefore being divergent, and all air being removed from the receiver, on bringing the radium near no effect is produced on the leaves; but immediately air or any other gas is admitted, they begin to collapse.

Another experiment, which is essentially similar to the foregoing, may be performed by electrifying an ordinary silk tassel (about 6 ins. long), by combing with an ebonite comb. The individual threads of the tassel, being similarly electrified, repel one another and consequently stand apart. On bringing the radium salt in proximity to the tassel, the threads fall together again.

The explanation is the same as that given of the electroscope experiment. The tassel, if placed in a vacuum, would not collapse on the approach of a radio-active substance. Plate IX (B) shows the tassel electrified, (A) collapsed.

The following is another experiment, on a slightly different principle, which demonstrates the con-



(A) Silk Tassel collapsed. (B) Silk Tassel electrified.

PLATE IX.—IONIZATION EFFECTS.

ductivity of the air, due to radium. An induction coil, (between the terminals of which sparks can pass), is taken, and the distance between the terminals is gradually increased by means of a micrometer, until it is just too great for the sparks to pass. The distance between the two terminals is then said to be just greater than the "critical" distance. On bringing the radium salts near to the spark gap, sparks at once pass between the two terminals. The explanation is, that radium renders the air between the two terminals better able to conduct electricity.

If the distance between the two terminals be decreased to just *below* the critical distance, and radium be brought near, sparks will no longer pass from the positive terminal (a metal knob) to the negative terminal (a disc); but a violet glow appears to surround the positive terminal. The explanation is that when electricity at a high voltage passes through a gas, it manifests its passage and the sudden breakdown of the resistance of the gas, by the passing of a spark. When it passes through a gas which has been rendered conductive, several different phenomena may be perceived, depending upon the conditions; but no *spark* will pass. The most probable manifestation will be the violet glow, already alluded to. If a piece of lead be interposed between the radium salt and the spark gap, the sparks will again pass as though the radium had been removed. If the disc be made of cardboard instead of metal, the arrangement is so sensitive that it will detect the presence of

a radio-active substance even when the latter is more than a yard away.

A gas does not lose its conductivity immediately after the removal of the radium. It is evident, then, that some definite change has taken place. This change is known as *ionization*.

Ordinary gases, in their normal condition, are non-conductors of electricity. A very high voltage is required to pass a current, and when this happens (as already stated), the breaking down of this resistance of the air is manifested by means of the spark that passes. Ordinary conduction, as by metals, is not possible in a gas. If, however, the gas by some means is "ionized," it becomes a fairly good conductor. Every radio-active substance has the power of ionizing gases. When a gas that has been ionized is passed through tightly packed cotton wool, through a fine metal tube, or across a strong electric field, it loses its power of conductivity. The gas may also be rendered non-conductive by bubbling through sulphuric acid. It is thus evident that this power of conductivity is due to something mixed with the gas and removed by filtration or otherwise. These "somethings" are called "*ions*." They are very small particles, carrying positive and negative charges of electricity, which are shaken off the atoms of the gas. These particles are probably of similar dimensions to the β-ray particles.

Although all three classes of rays ionize gases, it is the α-rays which are chiefly instrumental in the experiments above mentioned. They are absorbed

by the air, while the β- and γ-rays suffer considerably less absorption.

The number of charged ions produced by the rays depends upon the intensity of the radiation and upon the pressure of the gas. There is the same amount of ionization in all gases for an absorption of a like amount of energy. The absorption of the α radiation increases directly with the pressure and temperature.

Radium rays, in addition to the production of ionization in gases, also have the power of producing somewhat similar effects in *dielectric* liquids. A dielectric liquid is a non-conductor of electricity. This has also been proved to be the case with Röntgen rays. Some of the molecules of the liquid become ionized, and so render it conductive. The amount of ionization depends, as in gases, on the pressure, the intensity of the radiation, and the time of exposure.

Ionization, in the ordinary sense of the term, cannot take place in solids. There is one example, however, in which radium radiation causes a change in the resistance of a solid. The element selenium has its resistance to a current of electricity considerably lowered by exposure to ordinary light. After diffused light has fallen on selenium, the resistance of the latter to a current is only one-thirtieth of its original value. If selenium be placed about an eighth of an inch from a radium preparation, its resistance to a current falls nearly 10 per cent. in ten minutes, and takes two hours to recover its normal value after the removal of the radium preparation.

It has been stated that the α and β rays

both carry charges of electricity—the α positive, the β negative. Such being the case, why are bodies not electrified when the radiation falls on them and is absorbed? All bodies are surrounded by a layer of air; the latter becoming ionized, conducts the electricity away before it can accumulate on the body. If the substance were placed in a high vacuum, the rays would then charge it. Only one class of rays must fall on the substance, for if both kinds were allowed to do so, they would be to some extent neutralized.

To demonstrate the charge carried by the α-ray particles, the β-ray particles would have to be deflected by causing the rays to traverse a strong magnetic field (see below). It is much easier to demonstrate the charge of the β-rays, the α-rays having but little penetrative power, and, consequently, being readily absorbed. Fig. 10 shows diagrammatically the essential parts of the apparatus necessary. It was invented by Strutt.

A glass tube A contains a radium preparation R. This is suspended by a quartz rod B inside a large glass vessel. The tube A is smeared on the outside with a conducting layer of phosphoric acid. Two strips of gold-leaf G G are suspended from this tube. Strips of tinfoil T T are placed inside the outer glass vessel. These pass down the sides and are joined together at the bottom C, where they are placed in metallic connection with the earth by means of a platinum wire fused into the glass. The β-rays emitted by the radium pass through the glass tube

A, and charge the gold leaves G G with similar electricity. The result is that the leaves diverge, because, as already explained, they are charged with like electricity. The gold leaves diverge more and more as the charge on them increases, until finally

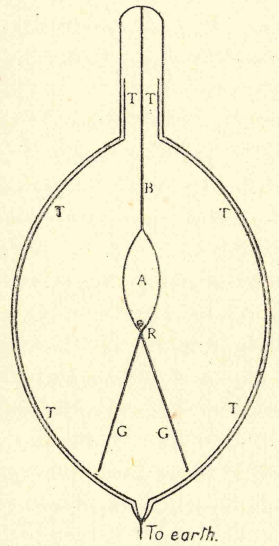


FIG. 10.—Strutt's apparatus for showing the effects of electrical charges carried by the β-rays particles.

each touches the tinfoil strips T T. The electricity instantly escapes through the tinfoil to the earth. The leaves, becoming discharged, fall together again and the cycle then recommences. It took at first twenty hours to complete the cycle, using a weak

radium preparation, but it has since been effected in four minutes.

It is quite certain that this effect is due to the β-rays, and not to the α- or γ-rays. The α-rays would be entirely absorbed by the glass tube A, and the γ-rays do not consist of charged particles. The experiment is very interesting, and it is probably the nearest approach to perpetual motion yet obtained.

The truth of the hypothesis that the β-rays consist of charged particles can be proved experimentally in a different way. When a conductor of electricity is proceeding at right angles to a magnetic field (the region between the poles of a magnet within which magnetic actions take place), it is acted upon by a force which tends to move it. It has been proved mathematically that a stream of charged particles should behave like a flexible conductor carrying a current of electricity. If the β-rays consisted of charged particles, they would, therefore, be deflected by a magnetic field. The following are three different methods of demonstrating the above :—

Becquerel's Method (*a*).

A block of lead, having a vertical saw-cut, in the depths of which is placed some radium salt, lies upon a photographic plate. The whole arrangement is supported upon one pole of a powerful magnet in order that the lines of force may pass at right angles to the radiation from the cut. Under ordinary conditions, the extent to which the plate will be affected

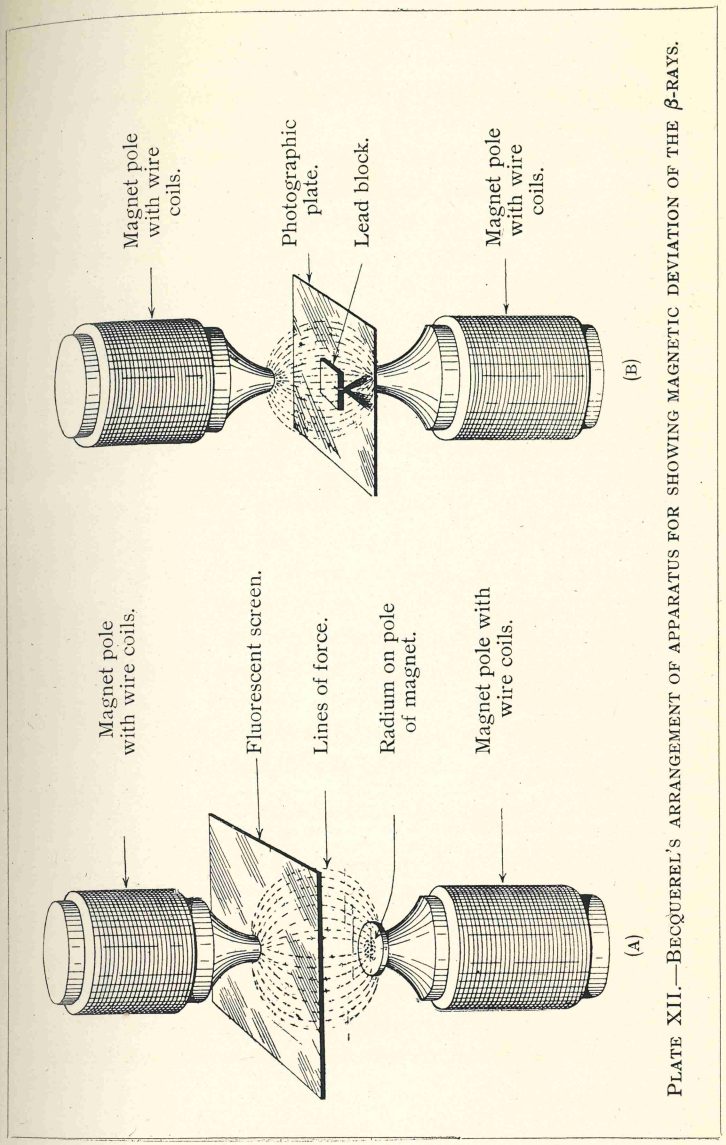


Plate XII.—Becquerel's arrangement of apparatus for showing magnetic deviation of the β-rays.

corresponds with the size of the orifice of the cut. The β-rays passing at right angles to the lines of force are deflected and affect the plate, forming a brush on one side of the strip produced by the radiation when undeviated (see Fig. 11). The direction of the

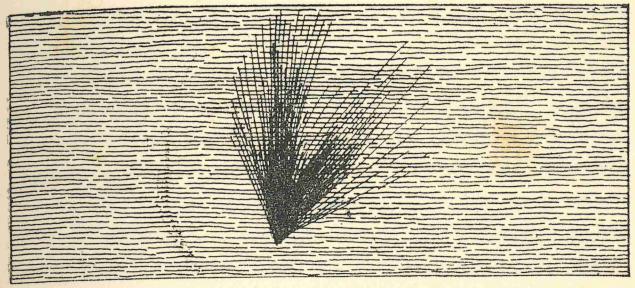


FIG. 11.—Illustrating magnetic deviation of β-rays.

deviation proves the charge carried by the particles to be negative. The arrangement of the apparatus used is shown in Plate XII (B).

BECQUEREL'S METHOD (*b*).

The effect of establishing the magnetic field; and thus producing a deviation of the rays, can be rendered visible to the eye or can be shown on a photographic plate as in method (*a*). Some radium preparation is wrapped up in aluminium foil and placed in the middle of an iron disc, forming one of the poles of a powerful electro-magnet. The other pole carries a fluorescent screen, consisting of a piece of cardboard coated with barium platinocyanide or

some other substance fluorescing under the action of the β-rays (see Chapter IV). The screen is placed about $\frac{1}{2}$ in. from the pole-piece. Only a faint and widely-dispersed luminosity is visible upon the screen before the current is turned on, *i.e.*, before there is any magnetic action on the rays. The luminous area greatly contracts and becomes considerably more intense on exciting the magnet. A photographic plate may be attached to the pole-piece instead of using a fluorescent screen : the effect in this case is very well shown. If the rays are *across* the region between the poles, instead of *along* it, they bend round like projectiles and impinge upon the plate along a curved line extending from one pole to the other, inclining away from the radium substance in the middle. The arrangement of the apparatus used is shown in Plate XII (A).

Curie's Method.

The demonstration in this case depends upon the ionizing effect produced upon the atmosphere. B B B (Fig. 13) are blocks of lead, a radium preparation R is placed between them. P_1 and P_2 are metallic plates kept at a potential difference of 500 volts, *i.e.*, a pressure of 500 volts is available for driving a current across the air space between them. This usually produces no measurable current, the air resistance being so great. The radium rays proceeding directly upwards from R ionize the air between P 1 and P 2, thus allowing an appreciable current to pass. This is demonstrated by the deflection of

a galvanometer included in the circuit with P and P. On establishing a magnetic field in a direction parallel to the vertical blocks the rays are deflected and are absorbed by the vertical blocks of lead—no ionization, therefore, takes place. This change is indicated by the deflection of the galvanometer falling to zero.

The α rays as well as the β may be deviated by a magnetic field. It is considerably more difficult to

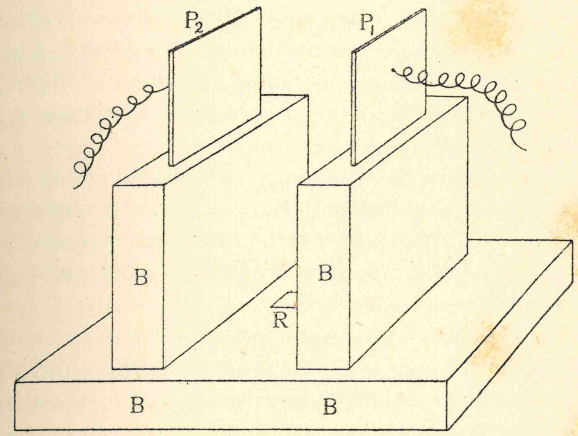


FIG. 13.—Curie's method of showing magnetic deviation of the β-rays.

demonstrate this, on account of the slight penetrative power of the α rays. It was at first believed that they were undeviable, but Rutherford and Becquerel have both shown that they are to a slight extent deviated by intense magnetic fields.

The following experiment shows conclusively the deviation of the α rays. A block of lead, with a vertical saw-cut in the depths of which some radium preparation is placed, stands on the pole of a very powerful electro-magnet. A sheet of lead with a vertical slit, corresponding in size and position to the orifice of the cut, is placed at a distance of $\frac{1}{4}$ in. from the block. A photographic plate is placed on the other side of the lead sheet.

The β rays are deviated to a considerable extent by the magnetic field. They therefore impinge upon the side of the sheet of lead, and are absorbed. The α rays being only very slightly deviated, pass through the slit in the lead sheet and affect the plate.

The current after a time is reversed: thus the polarity of the magnet changes and the rays are deviated to the other side. The plate shows on development an inverted V formed by the two lines of the deflected α rays.

The magnetic deviation of the α rays proves them to be composed of charged particles, and the direction of deviation shows that the charges carried are positive.

This last experiment might be performed in a high vacuum to show that the α rays carry a charge of electricity. An electroscope is placed in the position formerly occupied by the photographic plate. The β rays, being absorbed by the lead sheet, are eliminated from the experiment. The divergence of the leaves shows that the α rays consist of charged particles.

Plausible explanations can be given of the earth's electricity and magnetism on the assumption that the sun's radiation is due wholly, or in part, to the presence of radium (see Chapter II).

It has long been known that the higher regions of the earth's atmosphere are at a higher potential than the lower (this means that the electricity of the higher regions is positive compared to that of the lower regions). If the sun's radiation were due to radium, the α radiation, proceeding towards the earth, would be absorbed by the outer layers of the earth's atmosphere, thus charging them with positive electricity. The β radiation, being much more penetrative, would not be absorbed nearly so easily, and might reach the lower layers and the earth itself. This would account for the negative potential of the lower layers of the atmosphere and of the earth.

It has been experimentally shown that at night-time the potential difference between the upper and lower regions is considerably less than in daytime. Up to mid-day the outer layers of the air have been absorbing the α rays, while the β radiation has mostly passed through. This accumulation of positive electricity stops to a much greater extent the negatively charged β rays. A maximum effect is, therefore, produced about mid-day. The charges will be gradually dissipated as evening approaches, so that the potential difference diminishes.

Looking down upon the earth above the north geographical pole, the direction of rotation is counter-clock wise. If the negatively charged particles in the

lower regions of the atmosphere are carried round by the diurnal rotation, a magnetic field is thus established with the south pole in the position of the north geographical pole, and *vice versa*. It is well known that magnetic storms on the earth occur at periods of maximum sun-spot activity. This may be explained by the greater activity of the sun causing it to project electrons at a maximum rate towards the earth at such periods.

CHAPTER IV.

PHYSICAL EFFECTS (*continued*).

Luminous Effects—Spinthariscope—Fluorescent Substances—Thermal Effects — Thermo-luminescence — Penetrative Powers—Absorption of Gravitational Energy—Induced Radio-activity.

THE physical effects are all due either to the emanation or rays, rather than to the radium itself; it will, therefore, be more convenient to view the effects due to each class of rays separately.

The α-rays, moving with a very great velocity, cause certain substances to flash by their actual impact. This effect is beautifully shown by a simple little instrument invented by Crookes. Each form of the instrument, though differing in detail, is essentially similar. Typically, it consists of a short brass tube, carrying at one end a screen coated with hexagonal zinc sulphide. At a distance above the screen of about $\frac{1}{8}$ in. (which distance can be varied in some makes of the instrument) is a watch-hand, carrying on the side facing the screen a small fragment of radium nitrate. A short-focus powerful lens, magnifying about twenty diameters, is placed at the other end of the brass tube, whereby to view the screen. Fig. 14 shows one of Messrs. Beck and Co.'s spinthariscopes.

Were the screen to be viewed without the lens, it would present the appearance of a very faint glow; but if the instrument be taken into a darkened room, and the screen viewed through the lens, the appearance is that of a number of shooting stars. The screen appears as a black background covered with numerous scintillations, which are continually flashing forth, only to die away again. For this reason, Crookes proposed to call the instrument a "spinthariscope," from the Greek word *spintharis*—a

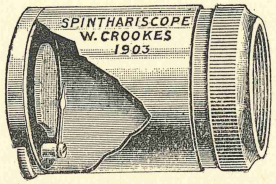


FIG. 14.

scintillation. The flashes are most numerous in the middle of the screen, directly underneath the fragment of radium, and they decrease in number towards the edges. Each flash is believed to be due to the impact of a single α-ray particle. The experiment is absolutely unique in showing the effects of bodies of atomic dimensions, for, as already stated, the α-ray particles are believed to be actual helium atoms.

Only a very minute fragment of radium, probably not more than a one two-thousandth part of a grain in weight, is used in practice. The radium is applied by dipping the watch-hands—a large number of which are coated at the same time—into a solution of

radium nitrate in water. Each watch-hand takes up a drop of the solution, and the water in evaporating leaves the radium behind. This experiment shows the perpetual character of the radium radiation.

The following theory—probably the correct explanation—has been suggested to account for the spinthariscopic appearance: It is supposed that each α-ray particle, in striking the small zinc sulphide crystal on which it alights, breaks it up into smaller crystals, which causes a flash of light, probably due to electrical charges generated by the cleavage .

That certain crystals, in breaking, do emit a flash of light can be readily verified by experiment. If a glass bottle, containing crystals of uranium nitrate, be shaken in the dark, many flashes of light will be visible, each crystal in breaking giving forth a flash of light. On scratching a screen coated with zinc sulphide with a piece of mica, many flashes are visible, due to the cleavage of the crystals. If a piece of lump sugar be crunched between the teeth, flashes of light are visible in the dark. These experiments prove conclusively that light, probably due to electricity, is evolved by the cleavage of crystals.

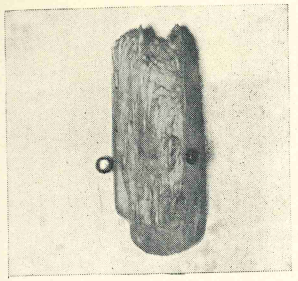
The following is a simpler method of constructing a spinthariscope than the above: The zinc sulphide screen is replaced by one coated with a mixture of powdered zinc sulphide and a non-luminous radium preparation. On looking through the lens in a dark room the constant discharge of radium electrons can easily be seen. The instrument may also be

used as a microscope slide and viewed in an ordinary microscope.

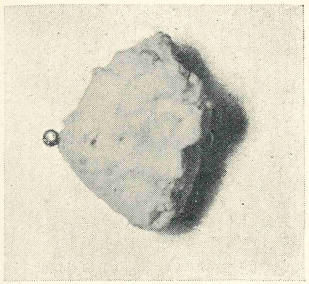
The spinthariscopic effect can only be shown to one person at a time, and cannot be projected on a screen, or rendered visible to a large audience. This is a great drawback to lecturers. Sir Oliver Lodge has partly surmounted the difficulty by imitating the spinthariscopic effect artificially. Two discs of metal, pierced with a large number of minute holes, are placed between the condensing and projecting lenses of a lantern, in the position usually occupied by the slide. On slowly moving the two discs relatively to one another, an effect of numerous, quickly disappearing, scintillations is produced on the screen. This gives a fairly good idea of the appearance of the screen in a good spinthariscope.

Several luminous effects produced by the β-rays are very striking. They cause many substances to fluoresce. This luminosity is probably due to a transformation of the kinetic energy of the particles (due to their motion) into energy in the form of light.

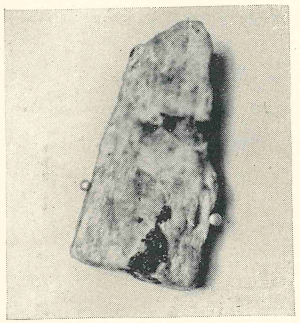
In every example hereinafter mentioned, it is probable that the effect is partly due to the α-rays as well as to the β-rays. If the fluorescent substance is held a short distance away from the radium, the glow becomes very much dimmer, and in most cases is absolutely invisible at quite a short distance. Were the effect due *entirely* to the β-rays, it is probable that the diminution would not be so marked, owing to the greater penetrative powers of these rays. The α-rays, on the other hand, are absorbed by an



(C) Kunzite.



(B) Artificial Willemite.



(A) Natural Willemite.

PLATE XV.—MINERALS FLOURESCING UNDER THE β-RAYS.

inch or two of air, and thus the great diminution of fluorescence when a short distance away *in air* is accounted for, if the effect is attributed partly to the α-rays.

Willemite, up to the present time, fluoresces more brilliantly under the action of the rays than any other substance yet investigated. This mineral [see Plate XV (A)] is a greenish opaque substance, somewhat like marble. Chemically, it is an anhydrous silicate of zinc, having the composition $ZnO\,SiO_2$. When a radium preparation is brought near to a piece of willemite, the latter appears semi-transparent, fluorescing with a fine green glow. The luminosity produced by the proximity of even so small a quantity of radium as one-thirteenth of a grain, sealed up in a glass tube, is quite sufficient to enable the time to be read on a watch in an absolutely dark room. If a piece of willemite is placed in the same vessel as the radium preparation, the glow is very much brighter, and appears to be due to the emanation. The explanation is probably the same as that given at the end of Chapter II, *i.e.*, less absorption of the rays causing the fluorescence.

Willemite is also prepared artificially. The luminosity of this artificial substance is, in some cases, superior to that of the natural mineral. Artificial willemite is a white lumpy substance (see Plate XV (B)).

The next best effect is probably the luminosity produced in good calcium tungstate. The fluorescence of the latter is very little inferior to that of willemite.

If a glass tube, containing a radium preparation, be inserted in a small glass bottle containing powdered calcium tungstate, the latter glows with a fine greenish light, very similar in colour to that emitted by willemite. Native calcium tungstate occurs as the mineral scheelite. Occasionally this is met with in the form of transparent colourless crystals, possessing considerable lustre. The luminosity produced in such a specimen is nearly equal to that of willemite.

One of the most interesting of the luminous effects is that produced in diamonds. It affords a ready method of distinguishing real from artificial stones. The former fluoresce brightly with a pale green light, whilst false stones or white sapphires (frequently used in their place) show little or no luminosity. This fluorescence is readily shown by holding a tube of radium bromide behind a single large diamond. If the latter is set in a ring, it has the appearance of a small lamp, shining pale green. All diamonds of equal size and value do not glow with equal intensity, some appearing much more luminous than others. This may be due to slight difference in their composition or in the cutting.

Another mineral fluorescing fairly well under the action of the radium rays is the recently discovered lilac-coloured variety of spodumene [Plate XV (c)]. This was discovered while investigating the optical properties of certain minerals, and was named "kunzite," after its discoverer, Dr. Kunz. A few

milligrams of radium bromide brought near to a piece of kunzite causes the latter to glow with a yellowish-pink light, which does not cease immediately on the removal of the radium, but persists for several seconds. It is chiefly interesting on account of the colour of the glow, as most minerals fluoresce with a greenish light under the action of radium. This property of fluorescence and subsequent phosphorescence is not displayed by any other varieties of spodumene yet examined.

The effect of radium on hexagonal zinc sulphide has already been mentioned at the beginning of this chapter. Besides the spinthariscopic effect, which (as already stated) is due probably to the cleavage of individual crystals, a true fluorescent effect is produced by the action of radium on zinc sulphide. The β rays cause the latter to fluoresce greenish-blue. This fluorescence generally predominates over the spinthariscopic effect, unless the quantity of radium present is very small : hence, it is important in spinthariscopes not to have too large a quantity of radium. The fluorescence produced is not very striking, and is indistinct in comparison with that of willemite or calcium tungstate.

Freshly-prepared ozone also causes hexagonal zinc sulphide to fluoresce brightly. This fluorescence continues for over 24 hours if the sulphide is left in a flask containing ozone, but it disappears together with the smell of ozone in 48 hours. As explained in Chapter V, ozone is produced in the presence of radium salts. It is possible, therefore, that the

fluorescence of zinc sulphide under the action of radium is a secondary effect due to the formation of ozone.

Barium platinocyanide, used with most effectual results with x-rays, is not so satisfactory when under the action of radium. It fluoresces with a yellowish-green light, not, however, so bright as that emitted by any of the substances already dealt with.

Uranium nitrate fluoresces faintly under the action of radium. There are also many other substances which possess this property. Mention has been made only of those which fluoresce most brightly.

Radium rays produce a general luminosity in the human eye. This effect is dealt with more fully in Chapter VI.

M. Curie found that, in addition to the continual emission of light, radium had the remarkable property of maintaining itself about 5° F. in temperature above that of the surrounding objects. This discovery aroused much interest in scientific circles. It is contrary to everything already experienced, for it is one of the laws of heat that, however hot a body may be, it will finally become of the same temperature as its surroundings. Radium appeared to be continually emitting energy in the form of light and heat—in fact, it seems to be a creator of energy. It has already been stated that the emanation is the source of both the light and heat emitted by the radium. Several theories have been put forth to explain this property; the one generally

accepted now is that some of the energy produced by the splitting up of the radium atom is evolved in the form of heat. Crookes has given another explanation. He suggests that the continuous maintenance of a higher temperature than that of its own surroundings on the part of the radium may be due to some atomic property of such radio-active bodies, whereby the slowly-moving molecules of the air may be thrown off with but a little exchange of energy, while the quickly moving ones may be stopped, and their kinetic energy, due to motion, converted into heat. It does not seem at all probable that this is the correct explanation. The other theory, that of energy emitted by atomic disintegration, appears more likely to be correct, and we have to imagine no such peculiar sorting property on the part of the radium to account for the energy which it emits.

Crookes' suggestion could be quite disproved if the radium were placed in a vacuum with a thermometer to register its temperature. Were it found (and such would probably be the case) that the excess of temperature of the radium above that of its environment remained constant, and did not decrease, then Crookes' suggestion would be proved incorrect, for the radium would have no air to draw upon for its energy.

The emission of heat and consequent elevation of temperature of radium, is easily demonstrated if there is a fairly large quantity of radium available for the experiment. Two glass vessels, each containing a thermometer, are enclosed in

cotton wool. One also contains some radium salt. After being left for some time, the thermometer in the vessel containing the radium will be found to register 2·7° C., or about 5° F., above that registered by the other thermometer.

When only a small quantity of radium is available, this property is not nearly so readily demonstrated. It might be shown in the following way: Two pieces of clear thermometer tubing of equal length are required. Bulbs of equal size are blown on the ends of each piece. Alcohol is then introduced into these "thermoscopes," and the quantities adjusted so that when the bulbs are standing on a plane surface, the menisci (or surfaces of the liquid) stand at the same height from the plane surface in each tube—*i.e.*, they are level. The two thermoscopes are placed side by side vertically between the condensing and projecting lens of a lantern, in the position usually occupied by the slides. A magnified image of the menisci is thrown on the screen, and as the thermoscopes stand on a level surface the images are level. The tube containing the radium is attached to one of the bulbs and well wrapped round with cotton wool. It will be noticed that the menisci no longer remain at the same level, but that a movement occurs showing that the radium is at a higher temperature than its surroundings. This effect cannot be due to any unequal heating of the bulbs by the lantern, since they need not be placed between the two lenses at all.

The amount of heat emitted by radium is such that

it will melt its own weight of ice per hour. For instance, a pound of radium would melt a pound weight of ice per hour for at least one thousand years. The amount of heat emitted has been measured experimentally by placing a known weight of radium salt in liquid nitrogen, the amount of heat emitted by the radium being ascertained by measuring the volume of nitrogen gas evolved in a given time.

Expressed mechanically, this indicates still more clearly the enormous amount of energy stored in the radium atom, which it emits during its life. A pound and a half of radium would supply sufficient heat, if this could all be utilized, to drive an engine capable of doing as much work as a strong man continuously for at least one thousand years, and perhaps for a much longer period.

Radium rays give rise to the phenomenon of thermo-luminescence in certain substances. The meaning of this term is best explained by an experiment illustrating this phenomenon. The thermo-luminescent substance, a mixture of calcium and magnesium sulphate, is coated on a thin piece of aluminium foil. The latter is covered with a piece of mica, and the edges of the aluminium foil are bent over to keep the mica covering in place. The screen is then placed, aluminium side down, upon a radium preparation, and the latter is allowed to act upon it for an hour or two. The screen is then transferred to a hot copper plate, when a green disc appears on the screen above the place where the radium lay.

The probable explanation is that the thermo-luminescent substance absorbs some of the energy emitted by the radium, and emits it in the form of light on subsequent heating.

No alteration in the intensity of the radiation from radium has been observed, even when exposed to the extreme cold of liquid hydrogen.

Another physical property of the radium rays will now be considered, namely, their power of penetrating substances opaque to light and other forms of radiation.

The penetrative power of the α radiation is very small, as compared with that of the β and γ rays. A few centimetres of air, a layer of glass, or a thin sheet of aluminum is all that is required to absorb it.

The β radiations are far more penetrative. If the theory of solar radiation being due to radium be correct, and hence that the lower regions of the air of the earth's atmosphere owe their negative charge to the β rays, it is a great proof of their penetrative powers, seeing that they are not absorbed by over fifty miles of the earth's atmosphere.

No substances can be said to be absolutely opaque to the radiations from radium. The opacity of substances to the rays apparently obeys the same laws as their opacity to κ-rays, *i.e.*, the denser a substance is, the less easily do the rays penetrate it. Lead is generally used as a screening or absorbing agent in experiments with the rays; gold would be better, and osmium (the heaviest known substance)

would be the most suitable; the two latter are not used on account of their cost.

The relative opacities of various substances to the rays may be studied by the following experiment: A and B (Fig. 16) are the terminals of an induction coil. The spark gaps 1 and 2, connected to A

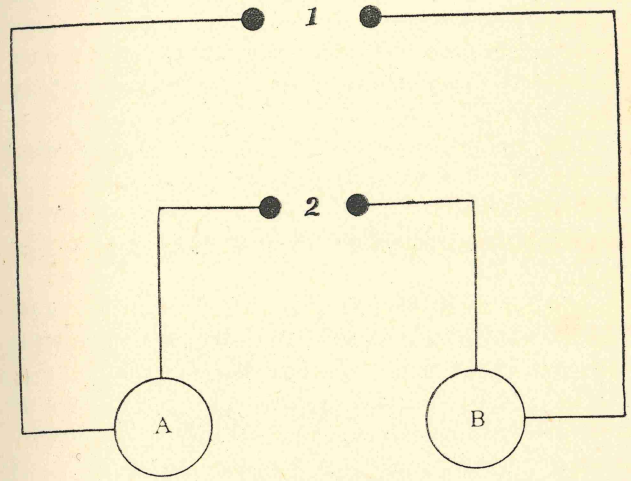


FIG. 16.—Diagram of spark gap experiment.

and B, are arranged as shown in the diagram. The lengths of the gaps 1 and 2 can be accurately adjusted by means of micrometer screws. By this means the spark gap 1 is adjusted so that it is just above its critical distance (see Chapter III), and the gap 2 is just below.

When in these positions sparks will pass at the

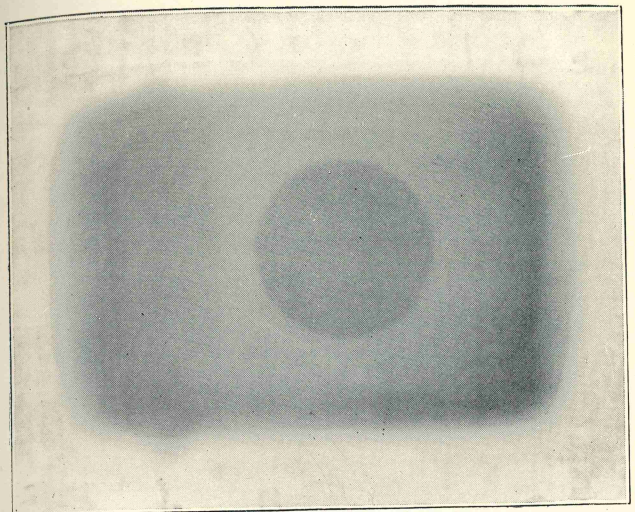
gap 2, but will just fail to pass at the gap 1. If some radium preparation be brought near to the gap 1, sparks jump across, while those before passing at gap 2 are much enfeebled, and quite disappear. This is due, as already explained, to the ionization of the air between the terminals of the spark gap 1, thus rendering its resistance to the passage of the spark less.

On bringing layers of various substances between gap 1 and the radium preparation, the sparks pass the gap, so long as the substances are not above a certain thickness, which varies with the substance. This " critical " thickness is a measure of the opacity of the substance to the rays—the more opaque a substance is, the less the critical thickness of the absorbing layer.

The relative differences in the opacities to the rays of various substances, differing in density, is well shown in Plate XVII (A). This is a radiograph of a sovereign in a silver matchbox, which was placed upon a photographic plate, wrapped up in two light-tight envelopes. The radium was placed about 1½ ins. above the matchbox, and allowed to act for several hours. Although both silver and gold are opaque to the rays, gold being much denser is far less easily penetrated, hence its shadow is cast upon the plate in the form of a circular patch.

The great penetrative powers of the radium rays, and their gradual decrease with equal layers of the absorbing substance, is well shown by Plate XVIII.

Plate XVIII (A) was obtained in the following



(A) Radium radiograph of a sovereign inside a silver matchbox.

(B) Photographic effect of induced radio-activity of a glass tube.

PLATE XVII.

way : A sheet of lead was pierced with seven holes ; this was laid on top of a photographic plate which was wrapped up in two light-tight envelopes. The radium was placed over the central hole marked O for two and a half hours ; it was then removed and placed over hole 1, over which a penny was placed, and exposed for the same time. This was then repeated over holes marked 2, 3, 4, 5, 6, over which were placed respectively 2, 3, 4, 5, 6 pennies. In the last case (hole 6) the rays passed through six pennies super-imposed and two light-tight envelopes before reaching the plate.

It will be noticed that the effect O, where the radium rays passed through only two light-tight envelopes, is very much more intense, in proportion, than that produced in the other cases, *i.e.*, the absorption produced by the first penny is very much greater than that produced by successive pennies. This is only to be expected, seeing that the α-rays would be entirely stopped by the first penny.

Plate XVIII (B) shows a similar experiment carried to a further stage. In this case, the exposures were always twelve hours for each hole. The numbers on the circles indicate the number of pennies super-imposed through which the rays penetrated before reaching the plate. In the case of circle 19, the rays passed through no fewer than nineteen pennies super-imposed and two light-tight envelopes before affecting the plate. The result already mentioned, namely, that successive pennies absorb a far smaller proportion of the rays than the first, is even better

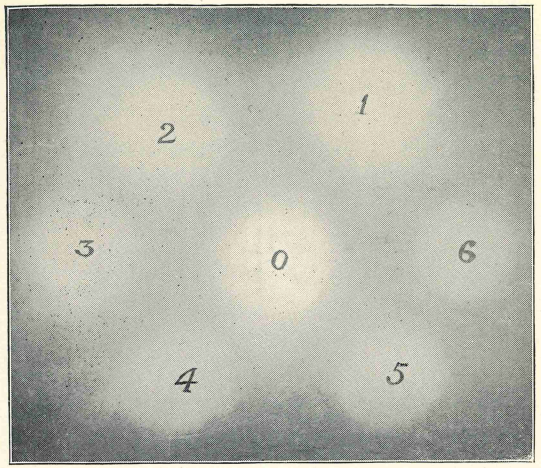
shown in this case. The addition of one penny after the first makes comparatively little difference to the effect produced.

In both cases it will be noticed that there is slight general fogging owing to the rays penetrating the lead block to a lesser degree.

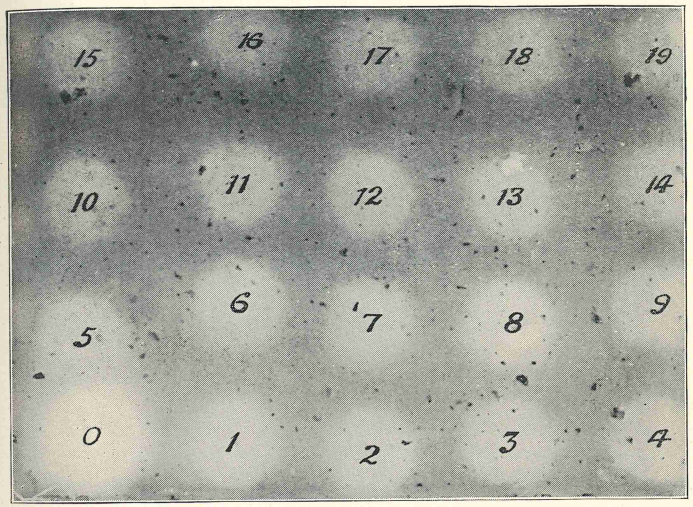
The β rays are fairly penetrative and the γ rays very penetrative. It is probable that the above effects are due mostly to the latter. The γ rays have been detected even after traversing several inches of lead.

It has been found that if a radium salt were placed underneath a lead block, the latter became measurably lighter. This was expressed by stating that absorption of gravitational energy was due to the radium. In an actual experiment performed, a lead block weighing 1·5 grs. appeared to lose ·000035 grs. when a gramme of radium chloride was placed underneath it. The loss of weight depended on the area of the radio-active substance. It seemed as though the upward bombardment of the particles emitted by the radium was the cause of this loss.

Recent experiments have cast grave doubts on the validity of these results. It was found that a block of lead lost in weight, when a dish was placed beneath it, *whether there was any radium in it or not*, provided that in each case the dish was put into position *with the fingers*. The effect, therefore, seems to be thermal, and to be due to ascending currents of warm air. When the experiment was conducted without causing any ascending currents of warm air, the loss of weight



(A) Exposure in each case, 2½ hours.



(B) Exposure in each case, 12 hours.

PLATE XVIII.—PHOTOGRAPHIC EXPERIMENTS ON THE PENETRATIVE POWER OF RADIUM RAYS.

suffered by the lead block was so small as to be quite within the limits of experimental error. The alleged dependence of the effect upon the area of the radio-active substance may be explained as depending upon the breadth of the ascending air current.

Other investigators have, however, obtained results in which the loss in weight is really believed to be due to the radium salt. The question is, therefore, still unsettled.

Radium has the remarkable property of inducing radio-activity in substances in its vicinity. This induced radio-activity appears to be due to a very thin film of emanation condensed upon the substance (see chapter on Emanation). This film can be rubbed off by sand-paper or dissolved off by acids; the radio-activity then appears in the sand-paper or acid.

The chief reasons for supposing that induced radio-activity is due to the emanation are: (1) Substances which emit emanations alone possess the power of inducing radio-activity in other substances; (2) if the emanating power of a radio-active substance is temporarily destroyed by heating for some time, the substance then loses its power to excite radio-activity in adjacent bodies; (3) radio-activity can be excited in bodies when only the emanation, and not the radio-active substance itself, is present. On the other hand, the power of exciting radio-activity by the radio-active substance itself is very greatly diminished if a stream of gas be led over

the radio-active substance, so leading the emanation away with it.

A characteristic property of induced radio-activity is that it can be confined to the kathode in a strong electric field. It is, therefore, probable that this radio-activity is due to the transport in the electric field of positively charged carriers of some kind.

This induced radio-activity is more intense if the radio-active substance be aqueous solution. The emanation is evolved much more freely when in this state.

Heavy metals are the best substances in which to excite radio-activity. The following experiment, in order to study the effect of the secondary radiation, due to induced radio-activity, was performed by Becquerel. A quantity of radium salt, forming a layer 1-16th in. thick, was placed in a groove in a block of lead. It was left in this position for eleven months. The lead block was then placed on a photographic plate, well protected by being wrapped in black paper, for forty-eight hours. On development an intense impression was found not only beneath the lead block, but also at some distance from its lateral surfaces. The rays had traversed a thickness of lead varying from $\frac{1}{2}$ to 1 in. A sheet of mica, placed between the lead block and the plate, guarded against any effects which might have been produced by the vapour emitted by the metal.

The secondary rays from heavy metals carry negative charges and to leave positive charges on the metal. In a vacuum these charges are

independent of the distance traversed, but in the presence of air molecules the charges dissociate the neutral electricity of the air into positive and negative, just as do the kathode rays and radium radiations.

Any kind of substance may be rendered radio-active, possessing all the properties of radium itself, so long as the induced charge keeps its potency. This fact may be of great value in view of the rarity and cost of radium. Any convenient object may, for a short time, be rendered radio-active, endowed with all the properties of radium, and be used in its place.

Plate XVII (B) illustrates the induced radio-activity of a glass tube by its effect upon a photographic plate. This tube contained a small quantity of radium bromide for a month. It was then removed, and the tube washed in nitric acid to ensure the complete removal of the radium. It will be noticed that the effect produced is very marked at one end of the tube. The radium rested at that end during most of the time. The washing in nitric acid probably diminished, to a slight extent, the induced radio-activity.

Substances rendered radio-active keep their charges very much longer when sealed up in a glass tube than when not so guarded. When sealed up, they lose half their radio-activity in four days and nearly all in twenty-eight days. When not so treated, they lose half in about half an hour and nearly all in $3\frac{1}{2}$ hours. To induce radio-activity in a substance, the latter must be in the same vessel

as the radium, otherwise the emanation cannot reach it.

The nature and quantity of the gas present in the vessel has no effect on the induced radio-activity. This result ceases to be true when, instead of a partial vacuum, a very perfect one is maintained by a mercury air pump, *working continuously* during the experiment. The body in this case does not become radio-active, and if already radio-active it loses that property. If the pump be stopped, the substance soon becomes strongly active again, and at the same time the pressure rises slightly. The collected gases are strongly radio-active.

All these effects are explained by the assumption that induced radio-activity is caused by the emanation. Unless the pump is kept working throughout the experiment, the emanation which is always being formed is not removed. This evolution of emanation also explains the rise in pressure when the pump has stopped.

CHAPTER V.

Chemical Effects.

Effect on Photographic Plates—Colourations of Glass, Paper, etc.—Effect on Solutions of Iodoform in Chloroform—Effect on Compounds of Iodine—Reducing Effect—Molecular Changes Produced—Relation to other Elements—Atomic Weight Determination.

Although only a few chemical effects produced by radium are at present known, it was really owing to one of these that its discovery was due. Becquerel observed the fogging of photographic plates by the rays from salts of uranium. This put Madame Curie on the road to her discovery (see Chapter I).

The action of radium on silver salts is exactly similar to that produced by light and x-rays. The silver salts on the plate are reduced to sub-salts. There is no change visible until after development, when a dark patch of reduced silver appears where the rays have acted upon the plate.

The time required to produce this deposit of silver on the plate depends upon the intensity and purity of the radium salt, and on the distance at which it is placed away from the plate. In Plate XIX (A) effect 1 is due to radium in its case being in contact with the plate for 5 seconds; effect 2 is produced similarly in 10 seconds, effect 3 in 15 seconds, effect 4 in 20

seconds, effect 5 in 25 seconds, effect 6 in 30 seconds. Effects 7, 8, and 9 were all produced in 30 seconds, the radium being respectively $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ of an inch away.

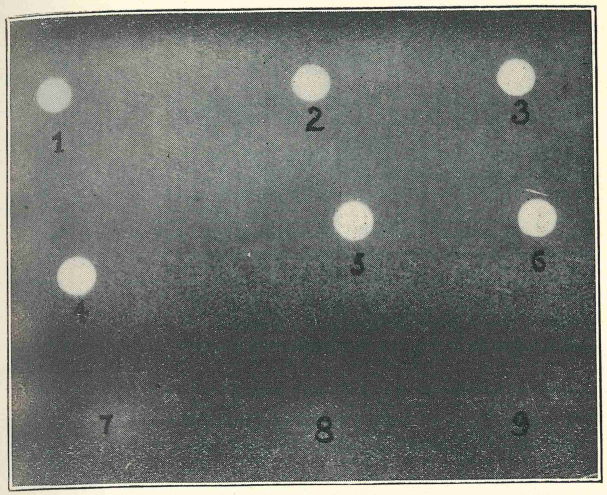
These nine effects illustrate the way in which the action varies with the time of exposure and with the thickness of the layer of air which the rays penetrate. It has recently been shown that the effects produced by the radium rays are even more closely allied to those produced by ordinary light than formerly supposed to be. A prolonged exposure to radium rays produces a reducing effect and a fainter image, just the same as in the case of light rays. A plate exposed to the light of an electric spark had its image completely reversed after exposure to radium rays.

Practically the whole effect produced on photographic plates by radium is due to the action of the β- and γ-rays, though doubtless the α-rays do, to a small extent, affect the plate.

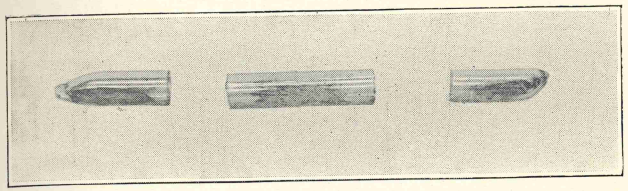
Many remarkable colourations in certain substances are produced by radium. The first to be noticed was that produced in glass.

A tube containing five milligrammes ($\frac{1}{13}$ grain) of radium bromide was coloured deep purple within the space of one month. Plate XIX (B) shows a glass tube which contained five milligrammes of radium bromide. The colouration is more noticeable if a solution of a radium salt be kept in a glass vessel; the emanation which is believed to produce this effect is more readily evolved in this case (see below).

The cause of the colouration was for a long time



(A) To illustrate the effect of the Radium rays on a photographic plate.



(B) Showing discoloration of glass.

PLATE XIX.

unknown. It is now believed to be due to the oxidation of manganese present in the glass. It is supposed that there is a disturbance of the chemical equilibrium existing between the manganous and ferric silicates present. This equilibrium is one pertaining to the high temperature of fused glass, and not to ordinary temperatures. Hence there is always a slight tendency to disturbance in this chemical equilibrium. This tendency is facilitated by the action of radium.

The above explanation is not the only possible one. The colouration may be due to a molecular change in the glass, or to some combination of the emanation with it; this last explanation does not seem at all probable on account of the non-combining powers of the emanation. The purple colour gradually darkens, until it becomes nearly black. The acquired tint is permanent unless the glass is raised to a red heat.

Porcelain and white paper are similarly affected by the radiations. Quartz, rock-salt, and potassium bromide become also discoloured. No explanation of these results has as yet been given.

Barium platinocyanide is normally a yellowish colour, which gradually darkens and becomes brown after exposure to the rays. At the same time, it loses its power of fluorescence. The action of sunlight, however, soon restores this last property.

Most compounds containing iodine, especially iodides, are rather unstable. They are easily decomposed by heat, light, or an electric current. It is

therefore to be expected that radium would decompose some of the compounds containing this element. Two only of these effects will be described here, but it is probable that there are many others similar.

A solution of iodoform in chloroform is decomposed by the action of radium. This solution is usually light yellow in colour. On placing a small quantity of radium bromide near to such a solution, no change is observable within twelve or thirteen hours, the exact time depending upon the conditions. When, however, this period has elapsed, the colour of the solution changes from light yellow to deep claret colour within the space of half an hour. The *entire* change can, however, be made to take place, under suitable conditions, within a quarter of an hour. This change can be shown on a screen for lecture purposes. A flat bottle, containing some of the unchanged solution, is placed between the condensing and projecting lenses of a lantern ; radium is then placed near to the bottle, and the discolouration is strikingly shown on the screen.

The change seems probably to be due to a breaking down of the iodoform with the liberation of iodine, which, by its solution in the chloroform, produces the claret colour. Formic acid is also probably produced by a combination of the remainder of the iodoform molecule with water (which is always present, unless special precautions be taken).

Another iodine compound, potassium iodide, is also easily decomposed. A damp piece of potassium iodide paper is exposed to the radiations for some

time. A blue colouration is produced, due to the liberation of iodine and its subsequent combination with the starch in the paper. This test is not nearly so delicate as the iodoform test, and, in addition, potassium iodide is very easily decomposed by many other substances, some of which are likely to be present in the atmosphere.

Iodine pentoxide has also been observed to be decomposed by the radiations. They also decompose nitric acid, producing a darkening in colour and the liberation of the lower oxides of nitrogen. These are both " endothermic " reactions (*i.e.*, reactions in which heat is absorbed to enable the molecule to decompose), and are caused by ordinary light.

Radium does not cause, as light does, the separation of insoluble sulphur from a solution of the soluble variety in carbon di-sulphide ; nor does it cause the condensation of acetylene into benzene as will the silent discharge.

It has for a long time been known that ozone is formed in the neighbourhood of an electric discharge. It is also produced in the presence of radium. This is an example of the transformation of an element into another allotropic modification. The ozone molecule is composed of three oxygen atoms—O_3, and the oxygen molecule of two atoms—O_2. Hence, this is a molecular rather than a chemical change. There is always a smell of ozone on opening stoppered bottles containing radio-active salts which have kept for any length of time.

Another example of this allotropic change is the

conversion of yellow phosphorus to the red variety. Yellow phosphorus is a poisonous, inflammable substance, of low melting point, and soluble in many essential oils, whilst the red variety is a non-luminous, very stable substance, which is not readily inflammable and is insoluble in most liquids.

The action of radium salts when dissolved in water is very interesting. They appear to decompose the water into its elements, oxygen and hydrogen. This apparent "electrolysis" has not been very fully investigated as yet. It is (like the formation of ozone and the decomposition of iodine pentoxide) another remarkable example of the enormous store of energy possessed by the radium atom. Its only practical application at present is to obtain the emanation for experimental purposes.

As already explained, the hydrogen and oxygen evolved carry with them minute portions of the emanation. In an actual experiment performed a solution of one gramme (15½ grains approx.) of 5% radium bromide liberated in sixteen days 3·5 cubic centimetres (¼ cubic inch) of gas containing 78% of hydrogen and 17% of oxygen. The solution was coloured with bromine. It has since been calculated that 5 centigrammes (not quite 1 grain) of radium bromide generates (or transforms) about two ft.-lbs. of work per diem.

Radium salts, like many other metallic salts, colour the flame of a Bunsen burner when vapourized in it. Chlorides of the metals are generally used, being the most volatile salts. In the case of radium,

the colouration is crimson. This colour is not characteristic of radium, as it is also obtained with strontium and lithium salts. The flame renders the surrounding air more capable of dissipating an electric charge, which phenomenon is not noticed with either of the other metals.

Radium salts are very similar to salts of the metals of the barium group. Their sulphates are insoluble in water (calcium sulphate is very slightly soluble), whilst their chlorides, bromides, and nitrates are all soluble. The similarity is also manifested in the appearance and crystalline formation of these salts. The chloride of radium is deliquescent, like that of barium and calcium. These are some of the reasons for assuming that radium belongs to this group of metals. It is therefore accounted divalent (*i.e.*, its atom has twice the combining power of a hydrogen atom), as the other three are known to be so. It was on this assumption that Madame Curie determined the atomic weight of radium.

The method adopted in this determination consisted in observing the weight of silver chloride obtained by precipitation with the purest radium chloride. The latter weighed nearly one centigramme in each determination. It was then added to some silver nitrate solution, and the deposit of silver chloride accurately weighed. The mean atomic weight was found to be 225.

As radium chloride is hydroscopic (*i.e.*, absorbs moisture), the weighing had to be rapidly performed.

The hydrated chloride obtained by crystallisation was heated to drive off any water present. When the weight was found constant it was raised to double the temperature. The weight still remaining the same proved it to be absolutely free from water. The precipitated silver chloride was radio-active and luminous, but there was no appreciable quantity of radium in it. This was shown by reducing the silver chloride to silver. The resulting silver was found to weigh exactly what it should do were the chloride pure.

Runge and Precht also determined the atomic weight from considerations based upon the spectrum of radium, and found it to be 257·8.

Neither of these determinations agree with what was expected from the periodic law of elements. This law states that elements of the same general properties have their atomic weight so related that, if any three elements of a group are taken in regular ascending order, the atomic weight of the middle one is half the sum of the other two. Thus, as radium is believed to belong to the barium group, its atomic weight should be about 234.

CHAPTER VI.

Actions on Animal Life and Living Tissues.

Effect on Plants and Seeds—on Spermatozoa—on Ova—on Eggs of the Sea-urchin—on Larvæ and Embryos—on Animals of Low Type—on the Eye—on the Skin—on Lupus and Cancer—Radium Apparatus for medical purposes.

Probably no branch of the study of the properties of radium is more interesting to the general observer than that of its action on animal life. Comparatively very little is at present known, but investigations are being carried on by several scientists, which we hope will, in the near future, add materially to our knowledge on this very important subject.

The action upon the lowest forms of organic life, *e.g.*, seeds, fungi, &c., will be firstly considered; after which its action on the higher animals, and finally its effect on human beings.

Radium rays appear to possess the power of arresting the growth of an organism. The fungi *Morticrella* was exposed for some time to the rays. It was found that the rays had entirely stopped the growth of the mycelium, *i.e.*, the part of the fungi bearing the spores which on germination give rise to fresh fungi. The action seems simply to stop the growth and not to interfere in any chemical way with the cell tissues. Nodules are formed in the

interior of the filaments and are evidently organs of defence against the radiations. The spores and mycelium are not killed, but will germinate as before, when placed under normal conditions.

The former can withstand great variations in temperature without the least ill-effect. It is very surprising, however, to find that seeds, usually well able to withstand adverse conditions (*e.g.*, immersion in liquid hydrogen), should be prevented from germinating by an exposure to the rays.

The actual experiment consisted in exposing seeds of the mustard and cress for one week to the radiations. They were planted, and, at the same time, "control seeds," *i.e.*, seeds not exposed to the radiations but quite normal, were planted as a test. It was then found, that the radiations had quite destroyed the germinating power of the exposed seeds, whilst 80 per cent. of the control seeds germinated. In this case, the radium appeared to have a directly harmful effect on germination.

Spermatozoa were exposed to the radiations, and were quickly destroyed. The latter are simply naked masses of chromatin, which is specialised protoplasm, the fundamental principle of life.

Ova, on the other hand, appeared to be more easily fertilised. A few of the unfertilised ova thus treated afterwards developed without the fertilisation of a spermatozoid. This fact is interesting, as hitherto only in a few rare instances has this been observed.

Radium rays appear to act on the chromatin network of the nucleus of the cell, augmenting or destroying its activity according to the length of the exposure. The chromatin network of the ova is protected by karyoplasm (*i.e.*, another form of protoplasm). This prevents the radium rays having a too powerful effect; simply causing the chromatin to be excited, and thus producing the development of the ova without the fertilising effect of the spermatozoa.

This fertilisation without spermatozoa is called "parthenogenesis." Hitherto it has only been observed in the *Aphis* (plant-lice) and drone bee. It is now doubtful whether parthenogenesis does really occur in either of these cases.

The effect of the rays has also been tried on unfecundated eggs (*i.e.*, eggs that have not been fertilised) of the sea-urchin. There are three stages recognised in the normal development of the eggs. The first is the "blastula" stage, and consists in the formation of a spherical ciliated membrane (*i.e.*, a membrane with microscopically small hair-like projections, which are in constant motion, around it). The second stage is the "gastrula" stage: here the development has so far proceeded that a cavity, known as the digestive cavity, has formed in the centre of the sphere. The third stage is the transformation of the gastrula into a freely moving larva, known as a "pluteus."

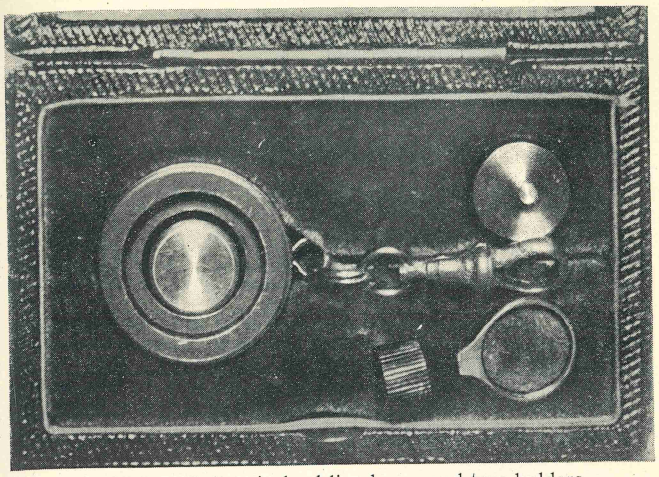
The rays were first employed after development had commenced in the blastula stage. The result was

to prevent the formation of the gastrula. It has, however, been found that segmentation (*i.e.*, the development of cells), which leads to the formation of the blastula, is accelerated or retarded according to the length of the exposure. This effect can be well understood when one remembers that in certain cases the effect of a small dose of certain alkaloids is beneficial, whilst in a larger dose it becomes a powerful poison.

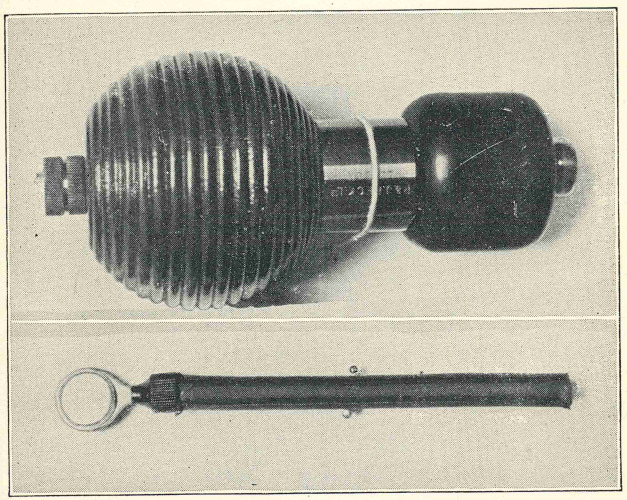
The effect was then tried after the gastrula stage had commenced. In some cases development was entirely arrested; in others it proceeded irregularly. Larvæ were obtained having the digestive cavity of the gastrula replaced by only an irregular mass of cells, in lieu of the normally straight alimentary canal. In some cases the mouth aperture only was formed.

The gastrula, when only exposed for a very short time, changed into the pluteus form; the development, as before, being accelerated by a short exposure. A normal pluteus was not formed, no limbs, used in natation, being developed. It seemed as though it had outgrown its strength, and become a weakling.

The larvæ of the *Ephestia Kuehniella* (little worms living in flour) were experimented on. Three or four dozen of these larvæ were placed in a glass flask with a little flour for the worms to live on. They were then exposed to the radiations for a few hours. The same number of larvæ were also placed in another flask, as a control experiment; the latter



(A) Radium Button in lead-lined case and two holders.



(B) Showing adaptors for external and internal use.

PLATE XX.—MEDICAL APPARATUS.

not being exposed to the radiations. After a few weeks the majority of the larvæ exposed to radium had died, but a few had escaped the fatal effects by crawling into the distant corners of the flask. These were still in the larvæ state, whereas normally, they should have long before developed into moths, and have hatched eggs into other larvæ. One of the exposed larvæ was alive four months after the exposure, having lived through three times the normal life, in its three transitions, of a fellow *Ephestia Kuehniella*.

The embryos of toads and frogs have been exposed to the radiations. The exposures lasted from three to six hours. The growth of the toad embryos, normally slow, was greatly retarded. Frog embryos, eight days old, rapidly changed into tadpoles, but became deformed in various ways, and could only be regarded as monsters, *i.e.*, abnormal deviations from the original type of the species. The breathing tentacles of normal embryos are changed into gills in tadpoles; but in those exposed to radium this change did not take place. There was an increasing atrophy (*i.e.*, shrinking) of the tail, and a peculiar wrinkling of the skin at the back of the head.

Young individuals do not at first appear influenced by the rays, but as soon as they have developed into tadpoles, deformities are noticed. The radiations killed a few of the embryos almost immediately. These effects are very similar to those observed on the embryo of the sea-urchin,

except that, in the case of the latter, the eggs were unfertilised, forming another example of the parthenogenesis accomplished by the aid of radium.

Thus it is seen that the chief action of the radiations is to supply energy to the reproducing cells. If the exposure is slight, a little energy only is absorbed, which simply serves as an excitement to growth; but should the exposure be increased, the effect is fatal.

Animals of low type have been exposed to the rays to determine as to whether the latter would cause an immediate contraction, or whether they would repel or attract the animals bodily.

The organism *Actinosphærium* did not retract its extended pseudopodia, which are arm-like projections extended for the purpose of catching food. The organism was exposed in daylight to the radiations from 10 milligrammes (·15 grains) of radium, at a distance of 3 mm. ($\frac{1}{8}$ inch). In two hours it was dead, whilst controls, not exposed to the radiations, were quite unchanged.

The Stentor and Hydra organisms were found to move bodily out of the path of the rays. Both *Hydra viridis* and *Hydra fusca* were experimented on. Weak specimens were killed.

Encysted (or resting) specimens of the organism *Euglena viridis* became motile by developing cilia under the influence of the β- and γ-rays, and dispersed without the least ill-effect. This encystation is a transformation peculiar to all protozoa, in which

they surround themselves with a thick coating and become motionless.

Radium produced paralysis when placed under the skin of a mouse near the spinal column. A microscopical examination of the effect produced on the latter showed the cause to be chiefly due to rupture of capillaries, *i.e.*, minute bloodvessels. The nerve substance was stained with blood, but presented no appreciable change.

On placing radium against the closed eyelid, a sensation of diffuse luminosity is produced. This luminosity is caused by the different parts of the eye glowing under the action of the β- and γ-rays. This glowing is not confined to the liquids of the eye, but also to the other tissues, skin, fat and muscle. If the radium be placed against the side of the forehead, the light will still be perceptible, although the rays have to traverse the frontal bone.

The screening action of the eyelid from the rays is equal to that of ·16 in. thickness of lead. The rays have no action on the visual purple of the frog and rabbit. The human eye is unable to discern the shape of the openings in a lead block, through which the rays are passing. This is due to the fluorescence produced in all parts of the eye.

Experiments on animals served only as a preliminary to those on human beings. Several eminent men have exposed their skin to the action of the rays. The total time of exposure was generally about ten hours; each single exposure being of less than two hours' duration.

The skin of the arm was generally, for convenience, experimented upon. It soon became red, having the appearance of a burn. There was very little, if any, pain. The redness was intensified after a few days, but had not spread. After twenty days a crust formed, which afterwards became a sore. The skin after forty-two days began to form around the edges of the sore, which, however, did not heal until the expiration of fifty-two days from the time of the exposure.

These experiments showed that the time for the effect of radium to be noticeable, depended on the intensity of the radiations, and the time of exposure. The action on the skin is thought to be caused by the radium producing a kind of anæsthesia or numbness on the peripheral nerves.

Radium affects the growth of all epitheliums, *i.e.*, membranes covering an external or internal free surface. This interference in the growth is caused by the epithelial cells becoming permanently modified by the action of the radiations.

Trypsin, the proteid-digesting ferment of the pancreatic-juice, had its activity appreciably increased by fourteen hours' exposure to the rays.

The foregoing experiments illustrate the difficulty in the treatment of cancer, lupus, and other skin diseases. The principal aim of medical men, interested in radium, is to so adjust the amount of radium and the time of exposure, as to obtain a maximum benefit from the application.

All malignant tumours are formed by an overdevelopment of cells. These perverted growths are

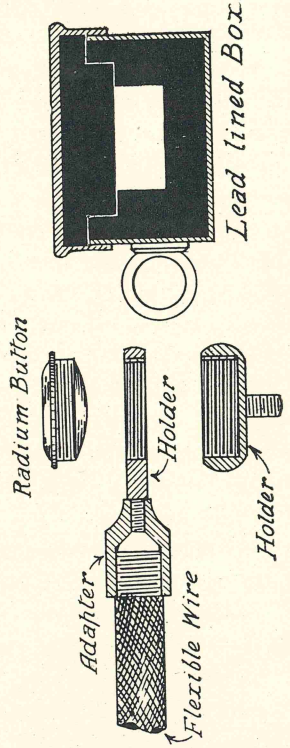


PLATE XXI.—DETAILS OF MEDICAL APPARATUS.

caused by a too great activity of cell production. The radiations are required to check this abnormal activity.

Patients suffering from lupus have been treated for over a year at the St. Louis Hospital, in Paris. The results have been fairly satisfactory—many patients being apparently cured. The treatment consists in placing for fifteen minutes at a time some radium, enclosed between two small discs of aluminium and copper, on to the affected part. This process is repeated daily for months. Whether these cures are absolute or not cannot at present be proved. Should they be permanent, this fairly rapid radium treatment will supersede the Finsen lamp, which, though giving very good results, is slow, and requires very costly apparatus. The aluminium disc of the radium case is only $\frac{1}{100}$ in. in thickness, and is pressed against the affected part. It allows a great part of the α- rays, as well as the β- and γ-rays to pass through.

Radium treatment for the cure of cancer has been going on for some time at the Fulham Cancer Hospital. The results have not been very satisfactory. Surface cancers were experimented on. The sores were photographed daily to mark the progress of the disease and the possible recovery. Treatment in these cases was conducted on very similar lines to that already described for lupus. Cures were effected, which are considered permanent.

The action was tried on deep-seated cancers. Every case experimented on was in an advanced

stage. At the end of a month the effects of the application were negative. The radium had apparently no effect in either causing or relieving pain. The irritation of the blisters caused by the radium was very slight.

It has been suggested that a strong application would act destructively on the disease. Radium in tubes could be easily introduced into accessible mucous cavities, such as the æsophagus and stomach. In the radium apparatus described below, manufactured by Beck & Co., radium is enclosed in a brass case, with an aluminium window.

The apparatus consists essentially of a radium button, two holders, an adapter, and a lead-lined box in which to keep the radium. The radium button consists of a brass case with an aluminium front, only $\frac{1}{100}$ in. in thickness, and, consequently, transparent to all the radiations. A lead backing, $\frac{1}{10}$ in. in thickness, is placed behind the radium. This acts as a screen to the rays. The outside of the button has a screw thread, whereby it can be placed in holders sufficiently small for insertion into the nostrils, larynx, &c. The holder for external application is an adapter with a wooden handle, carrying the radium at the end of a brass rod. A lead shield protects the hand from the rays. The distance of the radium from the affected place can be adjusted within certain limits. The holder for internal application consists of a gutta-percha rod, which can be bent into any required shape. Plates XX and XXI illustrate this apparatus.

It has been stated that radium can be successfully employed in the treatment of certain forms of neuralgic and rheumatic complaints. Pain in every case is removed by the action of the radium on the nervous centres. A case of facial paralysis was quickly cured after exposure to the rays.

The suggestion has been made that radium might be used in the cure of consumption. Air, rendered radio-active, could be inhaled which would have a detrimental effect on the bacteria. Extreme precaution would have to be taken in order to avoid harmful effects.

CHAPTER VII.

Other Radio-active Elements.

Uranium—Its Extraction—Appearance and Nature—Emanation—Uranium X—Rays Emitted—Their Effects.
Thorium—Nature—Thorium X—Emanation—Induced Radio-activity—Rays Emitted—Carolinium and Berzelium—Connection with Actinium.
Polonium—Discovery and Extraction—Physical Attributes—Rays Emitted.
Actinium—Discovery—Emanation—Rays.
Hofmann's Radio-active Metal.

Radium is by far the most radio-active of all elements. Several others possess in a greater or lesser degree this property of radio-activity. Some were known before the discovery of radium ; others, such as Berzelium and Carolinium, have but lately been discovered.

The properties of these other radio-active elements have not been nearly as fully investigated as those of radium. The elements dealt with in this chapter include uranium, thorium, polonium, actinium, and a radio-active element allied to lead. Considerably more is known about uranium and thorium than about the others, all of which are excessively scarce. It will be seen that their properties are similar, but that they differ greatly in the intensity of their radiations. Practically all of

them are more readily isolated than radium. They do not all emit the three classes of rays—α, β and γ ; some emit two, or even only one, of these rays. They all give off an emanation of lower atomic weight than the original element. The atomic weight of all radio-active elements is very high ; their spectra, being different, distinguish them.

Uranium.

Uranium was discovered in 1789 by Klaproth, who isolated the yellow oxide U_2O_3. It was named after the then newly-discovered planet Uranus. The metal itself was not obtained until a long time after. Pitchblende is the chief ore used in the extraction of uranium. Pure pitchblende is U_3O_8, but is usually found associated with a host of other substances.

Briefly the process of extraction is as follows : The arsenic and sulphur contained in the ore are first removed by roasting. Light metallic oxides are then removed by solution in hydrochloric acid. The purified ore is boiled with nitric acid, and subsequently evaporated with sulphuric acid. Uranium and other soluble sulphates are dissolved out with water. The uranium salt is obtained by processes of crystallisation.

Metallic uranium (obtained by reduction of dry chloride of potassium and uranium with sodium) is a white metal, fairly hard and very heavy.

Uranium has a very high atomic weight, viz., 240. Why elements with high atomic weights are

unstable has already been explained in Chapter II. We have now to consider, in greater detail, the product of the disintegration of the uranium atom. What this product is cannot be stated with absolute certainty. The radio-active residues separable from a uranium salt by fractional crystallisation from ether, called uranium X, is believed to be the first product of the decomposition of the uranium atom. This uranium X is very similar to radium. This fact has recently received additional support. It has been suggested that radio-active elements change into other radio-active elements. Thus, radium has been stated to be formed by the disintegration of the uranium atom. If such be the case, it is probable that uranium X is identical with radium, which consequently may be considered to be the first product of the decomposition of the uranium atom.

Uranium, or probably uranium X, emits two classes of rays, α and β, corresponding to the α- and β-rays emitted by radium. The third class, the γ-rays, have not yet been observed, and it is quite certain that, if they are emitted at all, they are exceedingly feeble.

The α-rays are detected by the ionizing effect produced in the atmosphere. Uranium salts slowly discharge an electroscope. The β-rays are demonstrated by their effect on a photographic plate. This latter can be made a very delicate test by sufficiently prolonging the exposure. Plate XXII (A) is obtained from a plate fogged by uranium nitrate crystals. The

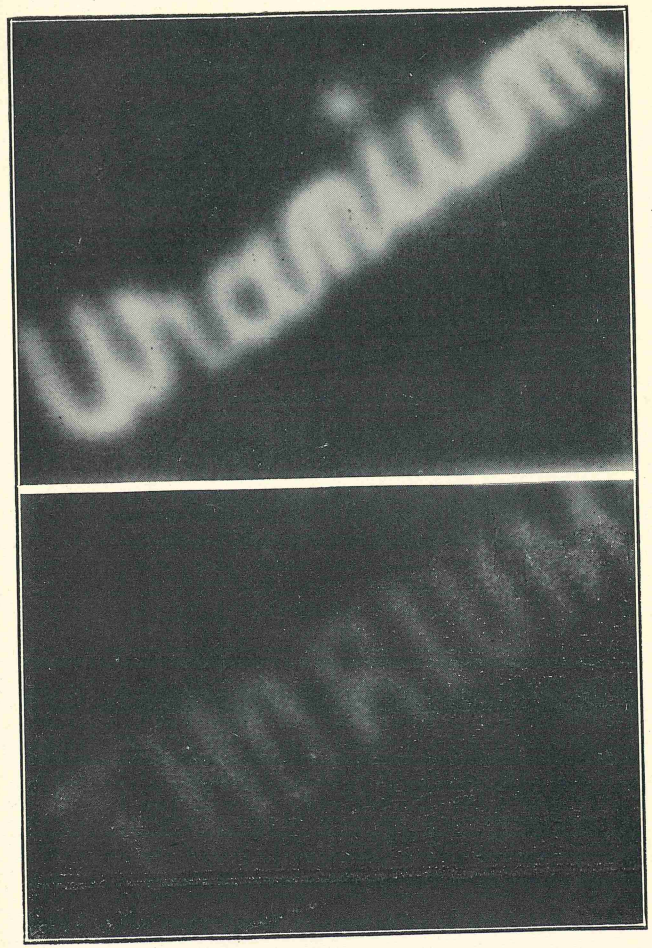


PLATE XXII.—COMPARATIVE PHOTOGRAPHIC EFFECT OF URANIUM AND THORIUM.

plate was protected from ordinary light by black paper, and the crystals were arranged to form the word "*Uranium*." The exposure lasted six days. Plate XXIII (A) was obtained by placing a piece of canary-yellow glass (which is coloured with uranium oxide) on a plate well protected from light. It is interesting, inasmuch as it is an example of a fairly common substance which is radio-active. The rays are deflected by a strong magnetic field, as described in Chapter III.

It has been estimated that uranium only loses one-thousandth part by weight in a million years. Thus it is evident that uranium has a much longer life than radium. It has been calculated that every gramme (15½ grains approximately) of uranium in pitchblende radiates in a million years at least 30,000 calories, which is enough heat to melt almost 1 lb. of ice.

It is possible that uranium itself is not radio-active, but only produces a radio-active substance. This radio-active substance may be either radium or uranium X.

THORIUM.

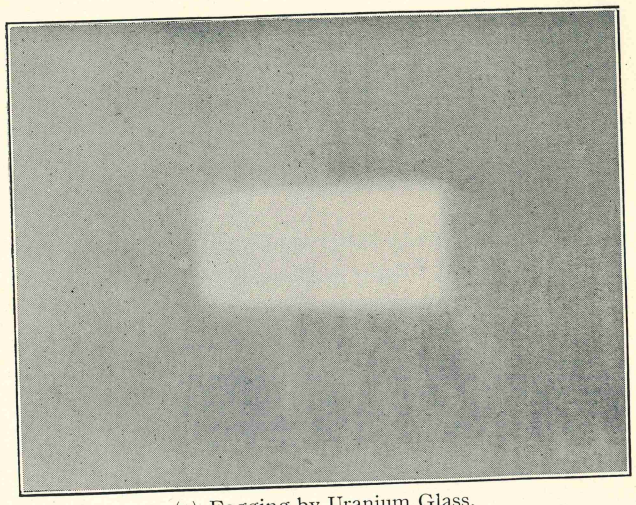
Thorium, until recently, was only known as a constituent of certain rare minerals. It has lately been isolated by reduction of a double fluoride (or chloride) of thorium and potassium with metallic sodium.

Metallic thorium generally occurs as a grey crystalline powder. Many of its salts are very similar in their physical characteristics to the corresponding uranium salts

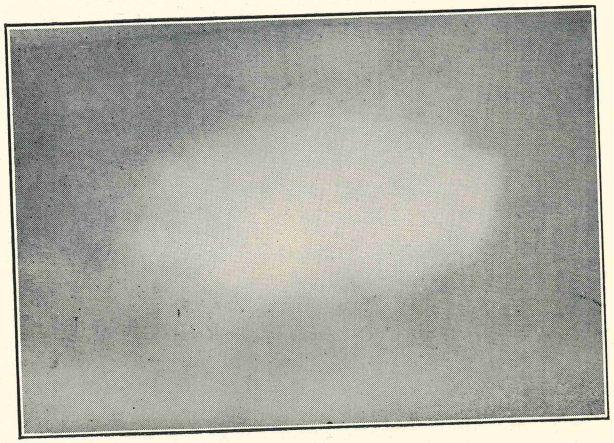
A great demand has been created for thorium dioxide within the last few years for the manufacture of incandescent gas mantles. The latter contain nearly 99 per cent. of thoria. Thorium has a very high atomic weight, viz., 232. Its molecule is, therefore, continually breaking down. The radio-activity of thorium was for a long while considered constant under all conditions ; it has now been found possible to separate, by a single chemical process, the greater part of this radio-activity. A precipitate of a thorium salt falls on the addition of ammonia to thorium solutions. This precipitate has but little radio-activity. The filtrate, on evaporation, yields a very radio-active residue called thorium X. The latter is a thousand times more radio-active than thorium. It is believed to be the first product of the decomposition of the thorium atom, also the source of all the radio-activity emitted by thorium.

The emanation from thorium is believed to be really due to the disintegration of thorium X. Its properties are very similar to those of the radium emanation. It has no power of chemical combination, and in this respect is also similar to helium. It is capable of condensation by great cold (– 120° C). It diffuses through porous materials, and may be bubbled, without absorption, through water and sulphuric acid. It, therefore, behaves like a true gas, and not like an assemblage of ions (see Chapter III).

Thorium X decomposes almost entirely in a month and loses its radio-activity. Thorium regains the power of radio-activity as fast as thorium X loses it.



(A) Fogging by Uranium Glass.



(B) Fogging by a Welsbach Incandescent Mantle.

PLATE XXIII.—PHOTOGRAPHIC EFFECTS PRODUCED BY COMMON RADIO-ACTIVE OBJECTS.

It is, therefore, evident that thorium forms thorium X as fast as the latter decomposes.

Thorium produces thorium X; thorium X produces the emanation, and the emanation produces the final product.

Thorium compounds, like those of radium, induce radio-activity on surrounding objects. The oxide has been found to possess this power in the greatest degree. The radiation emitted is homogeneous, penetrative, and confined to the surface. It is most probably due, as explained in Chapter III, to the emanation. Thorium compounds, when heated, lose their power of inducing radio-activity. This may be explained by the consequent evolution of emanation upon heating. This induced radio-activity is very similar, in every respect, to the induced radio-activity caused by radium.

An interesting experiment has lately been performed on secondary radio-activity in the electrolysis of thorium solutions. A deposit of highly radio-active lead peroxide is found on the positive pole in the electrolysis (*i.e.*, decomposition by electric current) of thorium nitrate. The radiations consist chiefly of α-rays. An emanation, practically identical with thorium emanation, is also simultaneously evolved. The negative pole bears no radio-active deposit. How the radio-active matter comes to be so closely connected with the lead peroxide has not as yet been explained.

Thorium emanation emits two kinds of radiations —α- and β-rays. The α-rays can be detected (as

already explained) by the ionization produced in the atmosphere. The β-rays are recognised by their effect upon a photographic plate. Plate XXII (B) shows a plate fogged by thorium nitrate so arranged as to form the word "*thorium*." The crystals were placed upon light-tight envelopes enclosing the plate. The exposure lasted six days—the same as that in uranium nitrate. It will be noticed, on comparing Plate XXII (A) and Plate XXII (B), that the fogging produced by uranium is considerably more intense than that due to thorium. Plate XXIII (B) shows a plate fogged by a Welsbach incandescent mantle. This is another example of a common radio-active object.

The life of thorium has been estimated to be about the same as that of uranium, viz., it loses one-thousandth part in a million years. It has been suggested that actinium is the active principle of thorium. So little is known about actinium that this suggestion cannot either be corroborated or refuted at present, but there is evidence to show that they are separate substances.

Thorium oxide prepared from such minerals as monazite, not containing uranium, is apparently not radio-active. It acquires radio-activity if exposed for some time to feebly active uranium. Experiments have just been performed confirming the conclusion that the degree of radio-activity is proportional to the amount of uranium contained in the mineral. Pure thorium oxide, prepared from a non-uranium mineral, failed to produce any effect upon

a photographic plate through thin black paper. Whether the radio-activity of thorium is only induced cannot be stated as yet with any degree of certainty.

The announcement has just been made (April, 1904), by Baskerville, that thoria is not a pure oxide, but is complex in its nature. He has isolated two new elements from thorium dioxide. One he has named "Carolinium," in honour of his native state, and the other "Berzelium," after the discoverer of thorium. Carolinium oxide is a pinkish powder; berzelium oxide is green. Both elements are radio-active, and are stated to be capable of application for illuminating purposes.

POLONIUM.

Polonium, one of the three intensely radio-active elements present in pitchblende, was discovered by Madame Curie during her researches on radio-activity. Analytically, it is very closely allied to bismuth, which is the last metal to accompany it before its isolation. They may be separated by any of the following methods: (1) If the two sulphides be sublimed in a vacuum, they condense (having different volatilities) at different parts of the tube. The polonium sulphide obtained has a radio-activity equal to four hundred times that of uranium. (2) If water be added to a strong solution of the mixed nitrates, the precipitate is more active than the salt remaining in solution. (3) Chlorides may also be used instead of nitrates in the above method, the precipitate, as before, being more radio-active than the solution.

The metal polonium has not as yet been isolated, and comparatively very little is known about it. On heating pitchblende (especially from Joachimsthal) in a porcelain crucible, a sublimate six times as radio-active as pitchblende is often found on the lid. Its radiations appear to correspond with those of polonium, and are not the same as those of radium.

Polonium emits two classes of rays, the α- and γ-rays; but no β-rays have been observed. Consequently, the radiations from polonium are practically undeviated by a magnetic field. A large amount of α radiation is emitted; hence ionization effects are fairly well marked. A spinthariscopic effect can be observed with a zinc-sulphide screen. The radiations also cause barium platino-cyanide to fluoresce.

The radio-activity of polonium preparations decay fairly rapidly, a marked difference in radio-activity being noted within the space of one year. It has recently been suggested that polonium is produced in one of the stages of the disintegration of radium.

Actinium and Radio-active Lead.

Actinium is a radio-active substance accompanying thorium extracted from pitchblende. It was discovered by Debierne. It has the power of exciting radio-activity in substances placed near it. In this and in many other respects it resembles thorium X. It was at one time supposed that actinium and thorium X were identical. The emanation from actinium lasts but a few seconds, thus differing from that emitted by thorium X.

Actinium evolves large quantities of luminous emanation. The latter is the source of a peculiar radiation emitted by actinium. This radiation is characterised by temporarily rendering bodies, on which it strikes, radio-active. These new rays can be deviated by electric and magnetic fields, showing that they consist of charged particles. The direction of deviation shows the charge carried by the particles to be positive. Actinium has not as yet been isolated, and its atomic weight is unknown.

Hofmann has separated from pitchblende and from some other rare earth minerals an element resembling lead. It is characterised by a radio-activity of about sixty-five times that of uranium, and an atomic weight which has been estimated at 260.

It emits both α- and β-rays, and can induce radio-activity in other substances.

APPENDIX.

EXPERIMENTAL APPARATUS.

[It is proposed to give in this Appendix a short account of a few pieces of apparatus, &c., suitable for experiments with radium. With one exception, they are all easily made, and are not at all expensive.]

A.—A Projection Electroscope.

It is often convenient to be able to project the image of the gold-leaves of an electroscope on a screen when demonstrating the ionization of the air, due to the presence of radio-active salts. Their motion is thus rendered visible to a large audience.

The following shows how to construct a simple electroscope suitable for projection in a lantern. The sides of the electroscope are composed of plain sheets of glass about $3\frac{1}{4}$ inches by $4\frac{1}{4}$. Spoilt quarter-plates answer the purpose very well. Care must be taken to select glass with no defects or flaws in it. The sides are separated by three strips of wood $\frac{7}{16}$ in. wide, $\frac{1}{4}$ in. deep, and of such a length that they fit together on the edges of the glass sides. We obtain thus a glass cell with wooden sides $4\frac{1}{4}$ ins. high, $3\frac{1}{4}$ ins. wide, and $\frac{7}{16}$ in. distance between the glass sides.

The gold-leaves are suspended from a brass rod about $\frac{1}{8}$ in. in diameter, carrying a brass ball $\frac{1}{4}$ in.

in diameter soldered to the top. The bottom of the rod is raised to a red heat, quenched, and then hammered flat to a width of about $\frac{1}{4}$ in.

The strips of gold-leaf are affixed to the flat part of the brass rod. They should be about $\frac{1}{4}$ in. in width and $1\frac{1}{2}$ ins. in length. The simplest way to cut gold-leaf to any required size is by placing it between two sheets of stiff white paper. If the pieces of paper, with the gold-leaf sandwiched between, be held up to the light, the position of the gold-leaf is clear, and it can then be readily cut. It is important to use gold-leaf, and not Dutch metal, the latter being not nearly so sensitive.

The mounting carrying the brass rod is composed of a collar of tapered brass tubing fixed vertically in the middle of the top of the case. The remaining space may be filled up with two strips of wood. A sealing-wax or paraffin plug is fitted round the brass, where it fits into the mounting. It should be of such a size as to move freely in the tapered brass collar. The taper prevents the arrangement from falling to the bottom of the case.

The brass rod is carried in a loose mounting in order to enable it to be turned round. By this means the sharpest and best image is obtained on the screen. This is a very important detail, and should on no account be neglected.

The electroscope is now complete, as far as working details are concerned. Its appearance is improved by binding the edges with a strip of black paper. It should not be kept in the lantern for too long a

period, as the heat may melt or soften the sealing-wax round the brass rod. An ebonite plug may be taper-turned on the brass rod, if preferred: it will be free from the above defect. On the other hand, it is not so good an insulator as sealing-wax or paraffin.

B.—Notes on the Construction of a Spinthariscope.

Spinthariscopes have already been described in Chapter IV. Sufficient details are given to enable

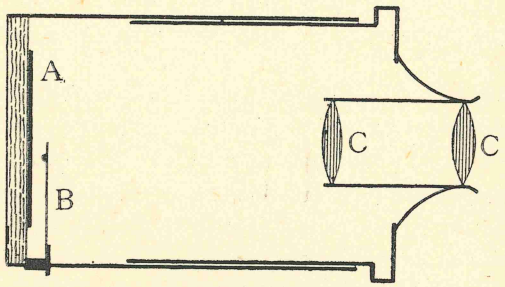


Fig. 24.—Details of spinthariscope.

the construction to be undertaken. The following notes may be of use :—

The Screen (A in figure).—This may be a circular piece of cardboard about ½ in. or less in diameter, coated with Sidot's hexagonal zinc-blende. It is better to coat the screen with salicylate of soda before the application of the zinc-blende.

The Needle (B in figure).—An hour-hand of a watch forms a very suitable carrier for the radium.

The mode of application of the latter has already been described. Radium nitrate appears to be more suitable than the bromide—it is easier to apply to the needles, and is more soluble in water.

The Lens (C in figure).—The forms of lens vary with the make. Some use Coddington lenses, which are corrected for spherical aberration. There seems to be no necessity for this, and such lenses are considerably more expensive than ordinary ones. A plain lens, magnifying about 12–15 diameters, is quite suitable. Crookes states, in his original paper, that he used a lens magnifying twenty diameters. It appears, however, that a lower magnification is more effective. The lens may be mounted so that it screws into the brass tube, and is focussed in so doing; or it may simply be carried by a lens tube of such diameter as to slide stiffly within the other.

The modification of a spinthariscope described in Chapter IV, in which a radium preparation is mixed with powdered zinc-blende, shows a somewhat different effect. The appearance presented, instead of the rippling effect produced in the ordinary forms, is more like one of bright flashes of light darting from an intensely black background. Owing to slight differences in the distribution of the radium, no two instruments appear quite the same.

C.—Special Case for Radium.

This was designed with two objects :—

(i) To obtain the largest amount of radiation with the least absorption.

(ii) It was preferable for the radium to be visible, so that its luminosity and other outward characteristics could be observed. Very thin aluminum is more transparent to all forms of radiation emitted by radium than any other substance.

The above requirements would be met by an ordinary glass tube, were it not that (i) glass absorbs nearly, if not quite, the whole of the α radiation and a small fraction of the β and γ radiations; (ii) it is discoloured by the emanation, and in time will become so dark that the radium will not be visible through it. It is, therefore, evident that glass is not a suitable substance for a radium case.

Fig. 25 shows, in section and plan, a special radium case devised so as to fulfil, as nearly as possible, the

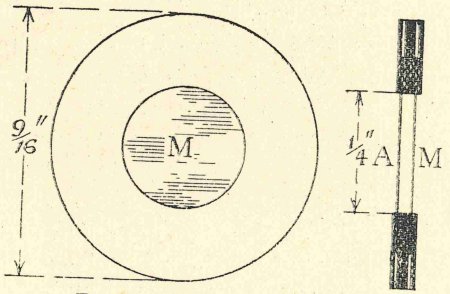


FIG. 25.—Radium case details.

above requirements. The bottom consists of two brass discs $\frac{9}{16}$ in. in diameter, with a $\frac{1}{4}$-in. hole in the middle. This hole is covered by a window of sheet aluminum $\frac{1}{500}$ in. thick, sandwiched between the

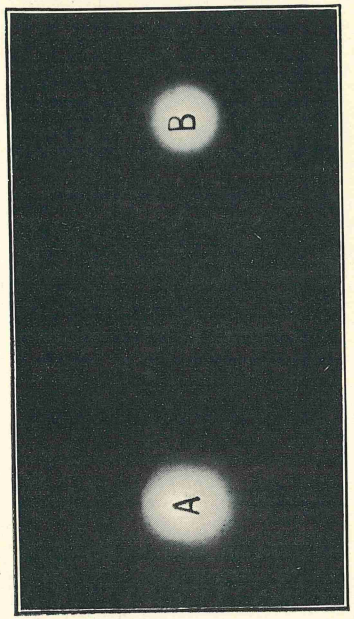


PLATE XXVI.—TO ILLUSTRATE THE GAIN IN PHOTOGRAPHIC EFFECTS DUE TO TRANSFERENCE OF RADIUM FROM A GLASS TO AN ALUMINIUM CASE.

brass discs, which are soldered together. This sheet aluminium is transparent to the β and γ radiations, and allows the majority of the α radiation to pass as well—a great advantage compared with glass. The thickness of the upper brass disc forms a cavity wherein the radium lies on the aluminium sheeting.

The lid of the box is exactly similar; but in this case the aluminium window is replaced by one of mica. The brass discs also are much thinner. Mica does not discolour like glass, and the radium can easily be viewed through it. The lid springs on to the bottom similarly to the closing of a watch-case.

Plate XXVI was obtained in order to study the effect of moving the radium from a glass tube to the case described. The radium in the glass tube was placed for five minutes upon a photographic plate, thus producing the patch A. After removal into the case, the patch B was produced similarly; the exposure being the same. This merely shows the gain (as evidenced by B being somewhat lighter than A) in photographic effect. When the radium was in the glass tube, the rays produced a large diffuse effect; but on its removal into the case, the effect became concentrated and more intense.

The photographic effect is not expected to gain much by the removal, being chiefly due to the β- and γ-rays, and not so much to the α-rays. It is in the luminous and ionization effects, produced chiefly by the α-rays, that there should be the greatest gain.

The walls of the glass tube are about $\frac{1}{20}$ in. in thickness. The aluminium is only $\frac{1}{500}$ in. thick; if

the absorption depended only upon the thickness, there might be twenty-five times less absorption. As a matter of fact, the greater part of the absorption takes place in the first absorbing layers. This fact must greatly modify the above estimate.

D.—A Uranium Screen.

The screen about to be described is useful for taking radiographs similar to those in Chapter I. Several other effects may also be produced. The following are two methods of construction :—

(*a*) *Uranium Fluoride Screen.*—A piece of glass, about 3 ins. by 4 ins. (such as a spoilt quarter-plate), forms the basis of the screen. Wooden sides are fixed with marine glue. A strong solution of about 200 grains of uranium nitrate is necessary. This is added to a nearly saturated solution of 50 grains of ammonium fluoride. Both solutions are kept boiling for a few minutes, added, and again boiled. A precipitate of uranium fluoride will at once form. The liquid should be cooled, the precipitate being kept from settling by continual stirring.

The solution with the precipitate suspended in it is poured, when nearly cold, into the dish already prepared as above. The precipitate will settle on the glass, leaving a clear liquid which should be removed with a syringe.

The precipitate is dried and the wooden sides are removed. An even coating of uranium fluoride should remain. This may be protected by covering with a varnish composed of celluloid dissolved in amyl acetate. The latter, on evaporation, leaves a very thin coating of celluloid to protect the surface from water, etc.

(*b*) *Pitchblende Screen.*—A piece of glass may be coated with a layer of powdered pitchblende. A very great deal, however, depends upon the radioactivity of the pitchblende used.

HAMPTON AND CO., PRINTERS, 12-13, CURSITOR STREET, LONDON, E.C.

X-Rays

SIMPLY EXPLAINED.

A Handbook on the Theory and Practice of Radiography.

BY

R. P. HOWGRAVE-GRAHAM,

Assoc. Inst. of Electrical Engineers.

Fully Illustrated with Six full-page Plates.

CONTENTS:

Historical and Explanatory.
Apparatus for the Production of Suitable Discharge.
Röntgen Rays Tubes.
Accessories.
Production of *X*-Rays.
Explanation of Terms used.

From all Agents of THE MODEL ENGINEER, *price* **6d.**; *or post free* **7½d.** *from*

PERCIVAL MARSHALL & CO.,

26-29, Poppin's Court, Fleet Street, London, E. C.

Simple Experiments in

STATIC ELECTRICITY.

A SERIES OF INSTRUCTIVE AND ENTERTAINING ELECTRICAL EXPERIMENTS FOR STUDENTS AND AMATEURS.

There are some 68 Experiments, describing the production of Electricity and its effects, etc., almost every Experiment having an illustration of the apparatus required.

ACETYLENE GAS:

How to Make and Use It.

This Book is a thoroughly practical guide to the construction of various types of small Generators, with hints on fitting up Pipes, Burners, and Purifiers.

The method of working a Gas Engine with Acetylene Gas is also described.

The Book is fully illustrated, and will prove of value to all interested in Acetylene Gas and its Uses.

Simple Scientific Experiments

A PRACTICAL HANDBOOK OF EFFECTIVE EXPERIMENTS IN ELECTRICITY, MAGNETISM, HYDRAULICS, HYDROSTATICS, LIGHT, ACOUSTICS, ETC., WITH SIMPLE HOME-MADE APPARATUS.

Describing 46 Entertaining and Instructive Experiments, fully illustrated by 58 Sketches.

The above Books may be obtained from all Agents for "The Model Engineer," price 6d.; or 7d. post free, from

PERCIVAL MARSHALL & Co.,

26-29, Poppin's Court, Fleet Street, London, E.C.

THE

MODEL ENGINEER and ELECTRICIAN.

EDITED BY

PERCIVAL MARSHALL, A.I.Mech.E.

Published every Thursday. Price 2d. Post Free, 3d.

A Splendid Paper for Young Engineers, Apprentices, Students, and Amateurs interested in Mechanics and Electricity.

Special Features:

Practical Articles by experienced writers on the construction and working of model steam, gas, and oil engines; model locomotives and railways; model boilers; model steam and electric launches, and sailing yachts; lathes and metal and wood-working tools; pattern-making; brass and iron founding; forging; model dynamos and motors; electric bells, telephones, and batteries; accumulators; electric lighting; influence machines; electrical experiments, etc., etc.

Model Engineers and their Work.—Illustrated Interviews with prominent model engineers, describing their workshops, their methods of working, and some of the models they have made. These are most interesting and instructive articles, and are fully illustrated from photographs.

Our Beginners' Column.—A section devoted to elementary instruction on the use of tools, the making of simple apparatus and models, and the carrying out of easy electrical and other scientific experiments.

Practical Letters from our Readers.—A correspondence column, wherein readers can describe workshop appliances or methods of their own invention, and discuss practical matters of mutual interest.

News of the Trade.—Under this heading short descriptions of new tools, apparatus, and materials are inserted, thus keeping the reader posted up in the latest improvements connected with his hobby.

A System of Queries and Replies, by which all readers of the Journal requiring information and advice on mechanical or electrical subjects can obtain replies by post within a few days. All replies of general interest are published in the following issue of the paper, so that while the individual enquirer can obtain the required assistance promptly, the remainder of the readers are not deprived of the interesting miscellany which a "Queries and Reply Column" always affords.

Original Working Drawings and high-class illustrations are a regular feature of the Journal.

Prize Competitions, open to all readers, are announced from time to time, the subjects of which are sufficiently diverse in character to suit the tastes of both mechanical and electrical workers.

Send 3d. for Specimen Copy.

PERCIVAL MARSHALL & CO.

26-29, Poppin's Court, Fleet Street, LONDON, E.C.

The Model Locomotive

ITS DESIGN AND CONSTRUCTION.

By HENRY GREENLY.

A Practical Manual on the Design and Building of Miniature Locomotives of all sizes.

276 pages, 370 illustrations, and 9 large folding plates of working drawings.

CONTENTS.

Chapter I.—Introduction; Choice of Scale and Gauge. Chapter II.—Locomotive Types. Chapter III.—Principles of Design. Chapter IV.—Boiler Design. Chapter V.—Frames, Bogies, Buffers, Axleboxes. Chapter VI.—Wheels, Springs, Cranked Axles. Chapter VII.—Cylinders and Valves. Chapter VIII.—Valve Gearing. Chapter IX.—Motion Details. Chapter X.—Boiler Construction. Chapter XI.—Boiler Mountings and Fittings. Chapter XII.—Cabs, Tanks, Tenders, Pumps, Injectors, Fuel, Firing Arrangements and Testing Apparatus. Appendix. Designs for Miniature Locomotives.

The only book dealing exclusively with the subject.

The illustrations are for the most part dimensioned scale drawings and include photographs of finished portions of model and small power locomotives.

Bound in Cloth. Price 6s. net; Post free, 6s. 5d.

PERCIVAL MARSHALL AND Co.,

26-29, Poppin's Court, Fleet Street, London, E.C.

"THE WOODWORKER."

PUBLISHED FORTNIGHTLY.

Price 2d. Post Free, 3d.

A PRACTICAL JOURNAL for all interested in

CARPENTRY,
JOINERY,
CABINET MAKING,
WOOD CARVING,
FRET-WORK,
MARQUETRY,
INLAYING,
WOOD TURNING,

and CONSTRUCTIVE and DECORATIVE WOODWORK of all kinds.
Illustrated with Photographs and Drawings.

Artistic Designs, Original Working Drawings, and Practical Articles appear in every issue. Send 3d. for a Specimen Copy. You will be pleased with it.

PERCIVAL MARSHALL & Co.,
26-29, POPPIN'S COURT, FLEET STREET,
LONDON, E.C.

EDUCATIONAL WOODWORK.

By A. C HORTH.

A COMPLETE MANUAL FOR TEACHERS AND ORGANISERS OF WOODWORKING CLASSES.

Bound in Cloth. Price 3s. 6d net. Post free, 3s. 10d.

For the convenience of teachers requiring instruction books for their students, the three yearly courses of exercises given in the above book are published separately in paper covers as under:—

SECTION I.—Course of Exercises for First Year Students. Price 4d. net. each. Per dozen, 4s. net.

SECTION II.—Course of Exercises for Second Year Students. Price 4d. net. each. Per dozen, 4s. net.

SECTION III.—Course of Exercises for Third Year Students. Price 4d. net. each. Per dozen, 4s. net.

PERCIVAL MARSHALL & Co.,
26-29, Poppin's Court, Fleet Street, London, E.C.

"THE WOODWORKER" SERIES OF USEFUL HANDBOOKS.

No. 3.—Joints in Woodwork. Fully illustrated. Price 6d. Post free, 7d.

No. 2.—The Beginner's Guide to Fretwork. With six full size original designs suitable for beginners, and numerous illustrations. Price 6d. Post free, 7½d.

No. 3.—Veneering, Marquetry, and Inlay. A practical guide to these interesting methods of decorating woodwork. Fully illustrated. Price 6d. Post free, 7½d.

No. 4.—Soft Woods and Colonial Timbers. Illustrated. Price 6d. Post free, 7d.

OTHER USEFUL BOOKS TO FOLLOW IN THIS SERIES.

PERCIVAL MARSHALL & Co.,
26-29, Poppin's Court, Fleet Street, London, E.C.

THE

"Model Engineer" Series

OF HANDBOOKS.

No. 1 Small Accumulators: How Made and Used.
No. 2. The Slide Valve Simply Explained.
No. 3. Electric Bells and Alarms.
No. 4. Telephones and Microphones.
No. 5. Electric Batteries: How to Make and Use Them.
No. 6. Model Boiler Making. FOURTH EDITION.
No. 7. Metal Working Tools and their Uses.
No. 8. Simple Electrical Working Models: How to Make and Use Them.
No. 9. Simple Mechanical Working Models: How to Make and Use Them.
No. 10. Small Dynamos and Motors: How to Make and Use Them.
No. 11. Induction Coils for Amateurs: How to Make and Use Them.
No. 12. Model Steamer Building: Hulls and Deck Fittings.
No. 13. Machinery for Model Steamers.
No. 14. Small Electric Motors: How to Make and Use Them.
No. 15. Simple Scientific Experiments.
No. 16. Acetylene Gas: How to Make and Use It.
No. 17. The Locomotive Simply Explained.
No. 18. Simple Experiments in Static Electricity.
No. 19. X-rays Simply Explained.
No. 20. Patents Simply Explained.
No. 21. Mechanical Drawing Simply Explained.
No. 22. Electric Lighting for Amateurs.

All these books are well illustrated, and contain Practical Information.

Price 6d. net each, from all agents for "The Model Engineer" and "Woodworker," or 7d., post free, from

PERCIVAL MARSHALL & CO.,
26-29, Poppin's Court, Fleet Street, E.C.

QD 181.R1 L579
Levy

AUTHOR

Radium and other radio-active

TITLE elements

DATE LOANED	BORROWER'S NAME	DATE RETURNED

Levy

RADIUM

L. A. LEVY
H. G. WILLIS

QD
181.R1
L579

PERCIVAL
MARSHALL
AND CO.

RADIUM:

and other Radio-active Elements

2/6 NET

LEONARD A. LEVY
HERBERT G. WILLIS